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FIELD TEST OF NON-INTRUSIVE TRAFFIC DETECTION TECHNOLOGIES

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ABSTRACT

Accurate, low-cost methods of collecting historical traffic information are essential in making well-informed transportation planning decisions. In addition, detection of real-time traffic conditions is a key element in advanced traffic management and traveler information systems.

Until the last decade, inductive loop detectors, pneumatic road tubes, and temporary manual counts were the primary methods for collecting both real-time and historical traffic data. However, technological innovations have given rise to design many different types of advanced traffic detectors. Recently developed traffic detectors use sonic, ultrasonic, microwave or infrared energy. Most of these detectors can be mounted overhead or to the side of traffic lanes. Magnetic sensors are now being built in sizes small enough to be placed in conduits under the roadway. Artificial intelligence algorithms can process videotaped images of road scenes and output many useful traffic parameters.

Even though non-intrusive technologies have been available for several years, there are still many uncertainties regarding their use. Traffic engineers lack a comprehensive comparison of the various types of traffic detection technology. A study conducted by the Minnesota Department of Transportation (Mn/DOT) and SRF Consulting Group, Inc. (SRF) and sponsored by the Federal Highway Administration (FHWA) seeks to address this need.

This paper describes a two-year effort to test non-intrusive traffic detection technologies. The purpose of this evaluation is to collect practical information on the performance, installation requirements, long-term maintenance requirements and costs of various types of non-intrusive traffic detection technologies. More than a dozen devices representing magnetic, sonic, ultrasonic, microwave, infrared and video image processing technologies will be evaluated during this project. Devices will be evaluated for their performance in both freeway and urban intersection monitoring situations.

Testing consists of two phases. During Phase I, which ran from November 1995 to January 1996, all participating devices measured traffic data on three lanes of Interstate 394 in Minneapolis at the Penn Avenue interchange. Phase II, which began in February 1996 and is scheduled to run through September, consists of an all-season monitoring of the devices' performance and maintenance requirements and will involve both freeway and intersection installations. The Minneapolis-St. Paul metropolitan area provides an excellent opportunity to evaluate the devices in many types of weather extremes, including very cold and very hot temperatures, rain, snow, fog, and high winds. This paper describes results from the Phase I test and initial results from one 3-week continuous traffic count from Phase II.

INTRODUCTION

Comprehensive information on the use of transportation facilities in urban areas provides the basis for decisions regarding transportation infrastructure. The accuracy of traffic data collected is extremely important because it affects funding priorities and the design of highway improvement projects.

Generally, traffic data needed to support the decision-making and design processes are traffic counts, vehicle classification, average travel speed, vehicle axle counts and lane occupancy. Inductive loops cut into the pavement are typically used at fixed location counting stations. Road tube counters and manual counts are typically used at temporary locations.

While traditional methods of traffic data collection are well-suited for rural applications, they can present difficulties and limitations in urban areas. Advantages and disadvantages of traditional data collection methods were summarized from surveys of twelve state transportation agencies: California, Connecticut, Florida, Georgia, Illinois, Michigan, Minnesota, New Jersey, New Mexico, New York, Ohio and Pennsylvania.

Fixed counting stations provide a baseline for traffic data collection. However, there are not sufficient resources available for enough fixed counting stations to provide all traffic counts needed in an urban area. In addition, loop detectors are not able to measure certain useful traffic data parameters, such as turning movement counts, complex weaving section movements and lane occupancy.

Staff safety is a concern when road tubes must be set where traffic volumes are high during daylight hours and relatively high during nighttime hours. Field personnel conducting manual counts are at risk if they must be exposed to traffic during the counts. Another problem results from personnel working in areas where crime presents a threat to personal safety.

Setting road tubes on moderate-volume roadways can result in temporary disruption of traffic flow. For high-volume roadways, road tubes are not typically used for counting because of the poor performance, high maintenance requirements and the difficulty of closing traffic lanes for tube installation.

Roadway geometrics can make it difficult to obtain accurate counts using road tubes. These geometrics include locations where there is significant lane changing or where vehicles do not follow a set path in making turns. Difficulties also arise when turning movement counts are needed over long periods.

The variety of weather conditions encountered pose significant problems with traditional data collection methods. Certain weather extremes, such as very hot or

very cold days, can limit people's ability to take manual counts. Road tubes also tend to malfunction in these extreme conditions. In addition, snow plows can destroy road tubes by scraping them off the pavement.

Finally, a complete picture of traffic data over a large region requires that numerous temporary count stations to be set up simultaneously. Using either road tubes or manual counts, these temporary mass deployments can be very expensive.

PREVIOUS NON-INTRUSIVE DETECTOR TESTS

Several previous studies have been conducted comparing different types of non-intrusive traffic detection technologies. The best-known and most recent is the *Detection* Technology for IVHS project conducted by Hughes Aircraft Company. The Hughes study tested 18 devices at eight different locations in three diverse geographic areas: Minneapolis, Minnesota; Orlando, Florida; and Phoenix and Tucson, Arizona. The focus of the Hughes study is significantly different that the project described in this paper, which examines traffic data collection at temporary sites. The purpose of the Hughes test was to determine if traffic detection technology currently available is sufficient for permanent data collection sites for Intelligent Transportation Systems (ITS) applications (1). While the Hughes test compared the performance of different devices in freeway versus arterial situations and in different environmental conditions, the study did not examine cost, installation requirements or long-term maintenance requirements of the devices.

Bolt, Bernenek and Newman, Inc. (BBN) conducted a comparison of infrared, sonic, ultrasonic, microwave and video detectors. BBN performed the test using inexpensive sensors developed exclusively for the project. During the course of the project, BBN also developed a data acquisition workstation capable of receiving input from many different sensors. The BBN study concluded that the strongest candidate for inexpensive replacement of magnetic loop detectors to provide vehicle presence, speed and classification, is a combination pulse ultrasonic and either doppler ultrasonic or doppler microwave (2) (see Project Definition of "Non-Intrusive" below).

An *Inside* ITS article reports that Indiana DOT is conducting a test of several different non-intrusive traffic sensors on the Borman Expressway in northern Illinois near Chicago (3). The Borman expressway has a very high percentage of truck traffic. The increased strain on the highway requires that the traffic lanes be repaved every five years. Illinois DOT is testing ultrasonic, infrared and microwave devices for a period of six to eight months, in order to determine which type of sensor would be well-suited for their permanent data collection needs.

The Center for Transportation Research (CTR) at Virginia Polytechnic University has a program to evaluate traffic detection technologies. CTR has an interim test facility that offers a variety of physical conditions. A permanent test site will be located at Virginia Tech's Smart Road facility when it is completed. CTR will study detectors' ability to collect both historical and real-time traffic information. The Center is developing a standard for traffic sensor technologies based on established measures of effectiveness.

The Southwest Technology Development Institute of New Mexico State University has proposed a National Test Center for Traffic Monitoring Devices. If funded by the Federal Highway Administration and the New Mexico State Highway and Transportation Department, the Center would also serve as a testbed for traffic detection technologies, both traditional and non-intrusive.

Several other universities and private consultants have conducted limited field tests of certain types of detectors. California Polytechnic State University has conducted two research projects through the California Department of Transportation (Caltrans) and California Partners for Advanced Transit and Highways (California Path). The first project tested commercially available video traffic detectors, including both tripline and tracking detectors (see Project Definition of "Non-Intrusive" below). The second on-going project is a study of infrared detectors, although the performance of the devices is not being examined. The University of Nebraska-Lincoln tested the Autoscope 2003 video sensor. The University of California at Berkeley a conducted field test of ultrasonic devices for freeway data collection. Ohio University examined the ability of ultrasonic devices to obtain intersection turning movements. The University of Texas at Austin examined the ability of infrared sensors to collect vehicle count, classification and weight information. The Texas Transportation Institute studied the performance of infrared 'and ultrasonic sensors.

PURPOSE OF THIS PROJECT

The purpose of this project is to evaluate devices' performance in collecting historical (rather than real-time) traffic data in urban (rather than rural) areas and at temporary (rather than permanent) locations. The purpose of this project is to review the capabilities of each type of traffic detection technology, not to compare products which use the same type of technology. For example, the Final Evaluation Report will not contain a brand to brand comparison of two passive infrared sensors.

Non-intrusive devices, as defined for the purpose of this test, are devices which cause minimal disruption to normal traffic operations and can be deployed more safely than conventional detection methods. Based on this definition, non-intrusive devices are devices that do not need to be installed in or on the pavement but can be mounted overhead, to the side of the pavement or beneath by "pushing" the device in from the shoulder. This definition includes sonic, ultrasonic, microwave, infrared and video-based devices, as well as magnetic devices which can fit in a conduit bored underneath the roadway.

DESCRIPTION OF NON-INTRUSIVE TECHNOLOGIES

Magnetic (Passive)

Magnetic detectors operate by detecting changes in the Earth's magnetic field caused by the presence of a vehicle. A vehicle's metal components, especially its engine, cause a magnetic flux when moved past a magnetic sensor. While magnetic detectors use the same principle as inductive loops, they can also detect a vehicle' volume, speed and classification, as well as presence.

Magnetic devices that attach to the surface of the roadway are subject to damage or dislocation by street sweepers and snow plows. Due to this limitation, this kind of magnetic detector was not evaluated in this project. However, magnetic devices that can be installed in a small (less than 3 inches wide) conduit bored underneath the pavement are included in the project's definition of no&intrusive technologies.

Infrared (Passive and Active)

Infrared devices detect infrared radiation (electromagnetic radiation with a frequency range of 10^{11} to 10^{14} hertz) which reaches the detector. Passive infrared devices detect the difference between the baseline amount of infrared radiation given off by the pavement and the greater infrared radiation emitted by the heat of a vehicle's engine as it passes through the device's detection zone. Active infrared devices transmit low energy infrared radiation to a target area in the pavement and detect the difference in reflected radiation between the pavement and a vehicle passing through the detection zone. Passive infrared devices can detect presence, density, speed, classification, occupancy and volume. Active infrared detectors can detect presence, volume, speed, density and classification.

Microwave (Radar and Doppler)

Microwave radar devices transmit a low energy microwave signal (electromagnetic radiation with a frequency range of 10^{9} to 10^{11} hertz) at a target area on the pavement which is then reflected back to the detector. The Federal Communications Commission limits transmission frequencies of traffic data collection devices to 10.5 GHz to 24.0 GHz (GHz = 10^{9} hertz). Pulse microwave devices, or radar devices, measure the time it takes for a portion of the microwave radiation to be reflected from the target area to a receiver. Continuous microwave devices, or Doppler devices, output a continuous signal to the detection zone and use the Doppler principle to analyze the change in frequency of the reflected signal to calculate the speed of the object. Doppler microwave devices can detect volume, presence and speed. Pulse microwave devices can detect volume, presence and occupancy.

The Doppler principle describes when the frequency of a reflected signal changes due to the speed of the object reflecting the sound energy. Because of the Doppler principle, whistles emitted by on-coming trains sound as if they are at a higher pitch than whistles emitted by departing trains.

Sonic (Passive Acoustic) and Ultrasonic (Pulse and Doppler)

Sonic detectors, or passive acoustic detectors, use a receiver to detect sound energy created by a passing vehicle to determine the presence of that vehicle. The device can also identify the classification of a vehicle by comparing the sonic signature created with a set of pre-programmed sonic signatures of vehicles of various classes. Passive acoustic devices have the advantage of working equally well in all lighting conditions and wide temperature and humidity extremes. They are also completely passive. Sonic devices can detect volume, speed and occupancy.

Ultrasonic devices transmit ultrasonic waves (sound pressure pulse with a frequency of 20,000 Hz) at a target area on the pavement which is then reflected back to a receiver. Similar to microwave devices, ultrasonic devices can be classified into two types: those that operate by pulse and those which emit a continuous signal and measure vehicle presence using the Doppler principle. Doppler ultrasonic devices can detect volume, presence and speed. Pulse ultrasonic devices can detect volume, presence and classifications.

Video (Tripline and Tracking)

Video image processing detectors use ‘artificial intelligence algorithms, embedded in both device hardware and software, to analyze the video image input. “Tripline” video detectors analyze the image of a target area in the pavement in order to emulate the operation of loop detectors. “Tracking” video detectors identify and track the movement of a vehicle entering the detector’s field of view.

Tripline video detectors can collect volume, speed, presence, occupancy, density, queue length, dwell time, headway, turning movements, acceleration, lane changes and classification. Tracking video detectors can collect all data parameters that tripline video detectors can collect, plus turning movement counts and origin-destination patterns within its field of view.

TECHNOLOGY REVIEW AND VENDOR RECRUITMENT

Over an eight-month period, Mn/DOT contacted 21 vendors, representing 26 non-intrusive devices to solicit their participation in this project. In order to participate in both Phase I and Phase II testing, most vendors volunteered to lend their devices to the project for one year. A few vendors, however, did not join the project until Phase II testing was underway. New products and product upgrades will be included as they become available to ensure that the tested devices truly represent the state-of-the-art of traffic data collection technologies.

Many device vendors were weary of yet another test program. Not only have comprehensive tests of different types of non-intrusive detectors been performed, many of the vendors' customers, i.e. state and local DOTs, insist on testing devices before buying them. The burden was then on Mn/DOT to distinguish this project from others by giving the following assurances to participating vendors:

- Mn/DOT and SRF are compiling monthly interim reports, sending them to both participating vendors and FHWA. The preparation of interim reports will assist Mn/DOT and SRF in publishing the project Final Evaluation Report soon after testing has concluded in 1996.

- Mn/DOT will paid the travel expenses of staff from participating vendors if they wished to visit the test site. Some vendors expressed dissatisfaction with previous tests because if a device malfunctioned, they were never given the opportunity to fix it.

- The Final Evaluation Report will emphasize information on which types of non-intrusive detectors are better in which types of situations, not which products out-performed their competition.

- A small amount of funding (up to $4,500) was set aside for each detector in case the vendor needed reimbursement to lend a very high-cost device. Even when presented with this funding opportunity, some vendors of very expensive systems declined to participate.

Table 1 contains a profile of each of the detectors considered for participation in the project.

TEST PLAN

Phase I - Initial Field Test

During Phase 1, which ran from November 1995 to January 1996, all participating devices except magnetometers were installed on a mounting structure on the Penn Avenue overpass of Interstate 394 in Minneapolis. Magnetic detectors were installed in a 3-inch wide conduit bored underneath the pavement. The devices measured traffic data in three lanes of interstate 394, including a reversible High-Occupancy Vehicle (HOV) lane. Figure 1 shows the data collection trailer and some of the devices installed on the mounting structure. Table 2 lists the devices tested in Phase I. A few of the devices are not intended for use in the single-lane freeway monitoring configuration setup in Phase I. Consequently, these devices were brought on-line but their performance was not compared to that of other detections in this freeway monitoring test.

The traffic data provided by the devices, including vehicle counts and average travel speed, were compared to baseline values collected by traditional methods. Loop detectors and radar guns provided baseline values. Weather conditions and general traffic conditions (free flow versus "stop-and-go") were also recorded. Methods of baseline data collection were compared to ground-truth methods, where possible, to ensure that they are collecting valid data. Detailed logs were kept to document any problems encountered with installation, set up and operation of the devices.

Phase II - Extended Field Test

Phase II, which began in February 1996 and is scheduled to run through September, consists of an all-season monitoring of the devices' performance and maintenance requirements. The devices' performance will be evaluated for both freeway monitoring, at the I-394/Penn Ave. site, and intersection monitoring, at a nearby intersection of Penn Avenue. Table 3 lists additional devices to be evaluated in Phase II. As in the Phase I test, the traffic data provided by the devices will be compared to baseline values collected by traditional methods. Mn/DOT will also record the time and expense it takes to maintain the devices during the year.

FIELD EXPERIENCES AND RESULTS TO DATE

Data Acquisition Software

After an initial investigation into what would be involved in designing and implementing a data acquisition system it was decided that the expertise of a consultant would be beneficial to the project. A request for proposal (RFP) was distributed to interested consultants and, based on these responses, Pioneer Technology out of Howell, Michigan was selected. Pioneer wrote the data acquisition system and provided extensive technical support.

A data acquisition software package, DT VEE by Data Translation, was chosen for the data acquisition system. This software was easily configured to acquire many types of data in a user friendly Windows environment. Some programming in Visual Basic or Visual C+ + was necessary to acquire all of the data formats. Additional software such as database and statistical packages was also used for the data analysis portion of the project. Vendor supplied software was used to process the data coming from some of the sensors. Figure 2 shows the display of the data collection computer with detection indicators, counters, a time/date clock and video inset window. This display is recorded to videotape during 48-hour counts.

The Peek ADR 3000 was be used to aggregate all of the relay data. It is a commercially available traffic data recorder that will be used to manipulate relay data from the following two sources: relay baseline data from the six inductive loops and relay data from the devices that emulate loops.

Data Collection

Baseline Calibration

Six loops previously installed for the Hughes Aircraft *Detection Technology for IVHS* study are being utilized for this project. They are located in both lanes of eastbound 394 and in the northern HOV lane. The loops are six feet by six feet square with the leading edge of one loop twenty feet from the leading edge of the next. The data from the loops serves as a baseline against which the output from all other devices is compared. in order to establish the accuracy of the loops the volume and speed outputs were checked against ground truth data collected by manual counts and speed observations.

One hour manual counts were conducted in five-minute intervals on several different days and under different traffic conditions. At the same time loop data was collected from each loop individually, allowing a comparison between the upstream and downstream loops in each lane. Each loop was found to agree very well with the loop in the same lane. The calibration results found the loops in lane one to undercount by 0.1 %, lane two to undercount by 0.1% and the HOV lane loops to undercount by 0.9%.

Speed data was collected with each pair of loops by measuring the time it takes for a vehicle to cross from the upstream loop to the downstream loop, twenty feet away. The automatic data recorder was used to calculate the speed and aggregate the data. The speeds measured by the loops were calibrated with a combination of a radar gun and a probe vehicle. First the speed of the probe vehicle was established. The probe vehicle's speedometer was found to agree to within one mph of the speed measured with the radar gun. The speed in the HOV lane was not calibrated because there are no devices in that lane that output speed data.

in the first calibration test the probe vehicle was driven through the detection area and at the same time an observer in the data collection trailer recorded the instantaneous speed as displayed by the automatic traffic data recorder. A cellular phone was used to communicate between the trailer and vehicle. The probe vehicle was driven at speeds ranging from 30 mph to 70 mph. Lane one was found to underestimate the speed by 6.1% and lane two to underestimate by 1.9%.

For the second test the radar gun was brought down to the shoulder of the freeway and aimed at traffic in lane two. During gaps in the traffic stream specific vehicles were singled out for speed measurement. At the same time an observer in the data collection trailer recorded vehicle speed as displayed by the automatic traffic data recorder. A cellular phone was used to communicate between the trailer and the radar gun operator. Thirty vehicles were observed in this manner and the loops in lane two were found to underestimate speed by 2.0%. Lane one and the HOV lane were not accessible for observation with a radar gun.

in the third test the radar gun was again located on the shoulder of the freeway. Speeds observed with the radar gun were read into an audio cassette recorder for a period of one minute. At the same time an observer in the data collection trailer collected speed data for the same lane and same time period. The data sets were then compared and the loops in lane two were found to underestimate speed by 2.4%. Again, lane one and the HOV lane were not accessible for observation with a radar gun.

Device Calibration

After devices were mounted, they were checked for basic functioning. Some devices simply output relay contact closure outputs and did not require any calibration. These outputs were compared to the outputs from the loops in the corresponding lanes. Most other devices require some degree of calibration. These devices were calibrated according to manufactures' instructions. informal data collection was done with these devices to aid in calibration.

48-Hour Traffic Count

Once all of the devices were found to be functioning properly, a 48-hour data collection test was conducted. The test began at 18:00 on November 20 and ran until 18:00 on November 22, 1995. Ail devices were tested simultaneously and the data aggregated into five minute time intervals. Some data output was in the form of a simple relay contact closure with the relay normally open and then closing when a vehicle was detected. Other data was supplied through a serial communication link to a personal computer housed in the data collection trailer. Some devices offered both data outputs, in these cases the serial data was selected for presentation. With the exception of two devices, all data outputs were successfully retrieved.

A data acquisition software interface consisting of a real-time display of ail relay contact closure inputs and a real-time video of the traffic in the test area was recorded onto VCR tapes during the test period. These tapes were made available to vendors for their use. The results from this test were provided to vendors for feedback in calibrating their devices. The results from this test are considered preliminary and will not be released.

3-Week Continuous Traffic Count

Shortly after the first 48-hour test, the data acquisition system was configured to collect data on a continuous basis in 15 minute time intervals. This continuous count was conducted from November 28 to December 18, 1995. Variables such as weather and traffic conditions were also noted for later comparison. In addition, three devices were not adjusted or calibrated from their original mounting positions so their outputs are considered valid. These devices are the radar, passive infrared and one of the doppier microwave. Refer to the "Findings to Date" section for results from this test.

Device Adjustments and Calibration

After the continuous data collection period was completed the data was prepared and distributed to vendors for their feedback and the devices calibrated according to their recommendations. Two devices were relocated to new locations. The video device was moved to the west end of the Penn Avenue Bridge in order to face oncoming traffic. The video device can count traffic in either direction but it is better suited for counting traffic at night when a vehicle's headlights are in the field of view. One of the doppier microwave devices was moved from the HOV lane to lane one in order to have it count heavier traffic.

Five other devices were re-aimed slightly from their existing locations. Ail of these adjustments were done according to vendors' recommendations, including one device that was found to have slipped from its original mounting position.

Three other devices, including two mentioned above, also required calibration adjustments to hardware or software settings inside the data collection trailer. These adjustments involved changes in sensitivity settings to calibrate counts and speeds. The three remaining devices were not changed from their original mounting locations.

24-Hour Traffic Count

A 24-hour data collection test was conducted on January 19, 1996. Data from ail devices and the baseline loops was recorded in five minute time intervals. When more than one data source was available from a device the serial data was selected for presentation.

One hour of traffic was manually counted to check the accuracy of the loops. The loops in lane one were found to overcount by 0.4% and the loops in lane two to overcount by 0.2%. These results are close to previous loop calibration tests and indicate the baseline loops are working properly.

Findings to Date

The results described in this paper are based primarily on the outcome of one 24-hour data collection period. Some technologies have been found to perform successfully while others have not done as well. Some of the results reflect problems involved in using the hardware and software elements of the data acquisition process and do not necessarily reflect a limitation of a particular technology. The full capability and limitation of each technology should not be inferred from the results presented here. Future testing, including additional devices, is needed to provide a more complete evaluation of each technology.

During the first continuous test period, November 28 to December 18, 1995 there was a significant snow storm on December 8 that produced subzero temperatures and left the Minneapolis area with 7 inches of snow. Associated with this storm was a reduction in vehicle speeds, a slight reduction in visibility, and a layer of snow on the pavement that obscured the lane striping. Vehicles were found to track outside of the normal travel patterns when snow was on the pavement. if vehicles were not driving directly over the loops the baseline data from these periods may be corrupted. Some devices were found to deviate substantially from loop counts during the storm. The passive acoustic devices were impacted the most, undercounting by an average of 75%. The passive infrared device undercount by 58% and the passive magnetic devices overcount by 22%. The doppler microwave, radar and pulse ultrasonic devices did not deviate significantly from the loops. The video device was not in operation that day. Over the next five days, from December 9 to 13, another 7 inches of snow fell and low temperatures ranged from -10 degrees to 9 degrees F. Again, the same devices were found to differ substantially from loops.

The 24-hour count results showed a tendency all devices to undercount vehicles by up to 10%. Figure 3 shows the result of the 24-hour count. Note the percent deviation data presented in this graph is the difference between each device and the loops in that lane. The correlation coefficient also shown in this figure provides a measure of each device's variation from the baseline data from one time interval to the next. The Pearson's product-moment correlation coefficient was calculated by dividing the covariance between each device and loops by the product of the device and loop standard deviations. The correlation coefficient measures the degree of deviation between the loops and each device. A value of 1 .O represents perfect agreement between the loops and a device. Some devices, particularly the doppier microwave and pulse ultrasonic, are accurate in the overall 24-hour counts and have a correlation coefficient close to 1. The tripline video, however, was close in its overall 24-hour count but had significant variation from one time interval to the next. The tripiine video's correlation coefficient was 0.78, showing a low correlation with the loop data.

The weather during the 24-hour count was partly cloudy and cold with a high temperature of -3 degrees F and a low of -18 degrees F. This day came two days after an ice storm left ice deposits on several of the devices. Despite the icy conditions the performance of most devices was similar to what had been observed in previous tests. The exception was the radar device that undercount by 7.1%. In the 21 day continuous data collection period the radar device ranged from undercounting 5.9% to overcounting 2.3%, averaging 1.5% low.

Speed data from this count period was available from one of the doppler microwave devices, the tripline video device, the radar device and the passive acoustic devices. Serial communication problems prevented retrieval of speed data from one of the doppler microwave devices. The loops in lane one gave an average speed of 31.3 mph. The passive acoustic device in this lane averaged 45.9 mph and the tripiine video averaged 30.9 mph. The loops in lane two gave an average speed of 31.6 mph. The passive acoustic in this lane averaged 44.4 mph, the doppier microwave averaged 36 mph, and the radar device averaged 34.7 mph. Other data that was received from the radar device included lane occupancy and two-class classification by vehicle length. This data has not been ground-truthed and is not ready for publication at this time.

The technologies that have performed basic count and speed data collection well to date are pulse ultrasonic, doppier microwave and radar. These technologies work well under varying environmental and traffic conditions. The devices representing these technologies are also relatively easy to install, calibrate, receive data from and are cost effective. The capabilities of the other technologies will continue to be explored during the Phase ii test.

NEXT STEPS

Phase II testing - Extended Field Trials - is now underway. In addition to expanding the test site to include a nearby intersection and evaluating the presence detection devices, the full range of capabilities of each device will be explored. Additional features to be tested are: vehicle classification, multiple detection zones, turning movement counts, and alternative mounting configurations such as sidemount poles.

At the conclusion of the Phase ii testing in 1996, Mn/DOT and SRF will compile data on the cost, performance, installation requirements and maintenance requirements of the various types of non-intrusive traffic detector technologies evaluated in this project. At this time, Mn/DOT and SRF will be able to determine which, if any, situations are better-suited for non-intrusive technologies than for traditional methods. In addition, the project will distribute guidelines which compare the different technologies in different situations, such as freeway versus intersection monitoring, extreme weather conditions, etc. Armed with this information, state and

local traffic engineers can be better-informed consumers when considering the use of non-intrusive traffic detection technology in their own state or region.

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TABLE 1 SUMMARY OF INFORMATION FOR DEVICES CONSIDERED FOR TESTING
FIELD TEST OF NON-INTRUSIVE TRAFFIC DETECTION TECHNOLOGIES

TECHNOLOGY	VENDOR/ PRODUCT	STATED CAPABILITIES	APPROXIMATE COST	ADDITIONAL EQUIPMENT REQUIRED
Active Infrared	Schwartz Electro-Optics, Inc. Autosense I	volume, occupancy, density, speed, classification, presence	$6,500	PC
Active Infrared	Santa Fe Technologies/Titan SmartLOOK	volume, presence, classification, acceleration, speed	$*	
Passive Infrared	Eltec Instruments, Inc. 833/842	833: volume, occupancy, speed, presence 842: volume (up to 45 mph), occupancy, presence	833: $820 842: $1,210	
Passive Infrared	Grumman Corporation Grumman Traffic Sensor	volume, occupancy, density, speed	$*	
Passive Infrared	ASIM Engineering, AG IR-222	volume, occupancy, speed, presence	$1,400	PC
Passive Magnetic	3M Microloop	volume, occupancy, presence, speed (with two sensors)	$500- $800*	
Passive Magnetic	Nu-Metrics NC-40 and NC-90	NC-40: volume, occupancy, presence NC-90: same plus speed, length, gap, temperature, wet/dryness	NC-40: $550 NC-90: $895	PC, IP10 Interface Card ($450), software ($450), tape coats (50 for $70)
Passive Magnetic	Safetran Traffic Systems, Inc. 232 E / 231 E	volume, occupancy, speed, presence (232 is the counter) (231 is the probe)	232E: $700 231E: $90 ea	PC
Radar	EIS, Inc. RTMS X1	volume, occupancy, speed, presence, turning movements, classification	$3,500	PC
Doppler Microwave	Microwave Sensors, Inc. TC-20 / TC 26B	volume, occupancy (20 is short range) (26B is long range)	TC-20: $630 TC-26B: $735	
Doppler Microwave	Peek Traffic, Inc. PODD	volume, occupancy	$950	Mounting hardware
Doppler Microwave	Whelen Engineering Co. TDW 10 / TDN 30	volume, occupancy, speed (TDW is wide beam) (TDN is narrow beam)	$995	PC (optional for serial data)
Passive Acoustic	AT&T / IRD SmartSonic TSS-1	volume, occupancy, speed	$1,450	Mounting brackets, PC to receive speed and occupancy data
Pulse Ultrasonic	Microwave Sensors, Inc. TC-30C	volume, occupancy, presence	$560	
Pulse Ultrasonic	Sumitomo Electric USA, Inc. SDU 420	volume, occupancy, presence	$*	
Video Tracking	CRS, Inc. TAS 2	volume, occupancy, density, speed, classification, delay, presence, queue length, incident detection	$15,000- $18,000	486 PC, camera
Video Tracking	Condition Monitoring Systems Mobilizer	volume, occupancy, density, presence, speed, classification, delay, turn moves, headway, acceleration	$3,000- $5,000*	Camera
Video Tracking	3M Cruise		$*	
Video Tracking	EVA, Inc. 2000 S	volume, occupancy, density, presence, speed, classification, headway (Price varies with features)	$7,000- $17,000	386 PC, camera, software
Video Tripline	Econolite Autoscope 2004	volume, occupancy, density, presence, speed, classification, headway, turning movements	$24,000	386 PC, camera & accessories ($2350)
Video Tracking	Peek Traffic, Inc. VideoTrak 900	volume, occupancy, density, presence, speed, classification, headway, turning movements	$23,500	Camera
Video Tripline	Rockwell International TraffiCam	volume, occupancy, speed, presence	$3,800	386 PC
Video	Sumitomo Electric USA, Inc. IDET 100	volume, occupancy, speed, classification, presence	$15,000*	
Video	Eagle Signal / Odetics VTDS	volume, occupancy, speed, presence, headway	$*	

* Price is estimated or was not available

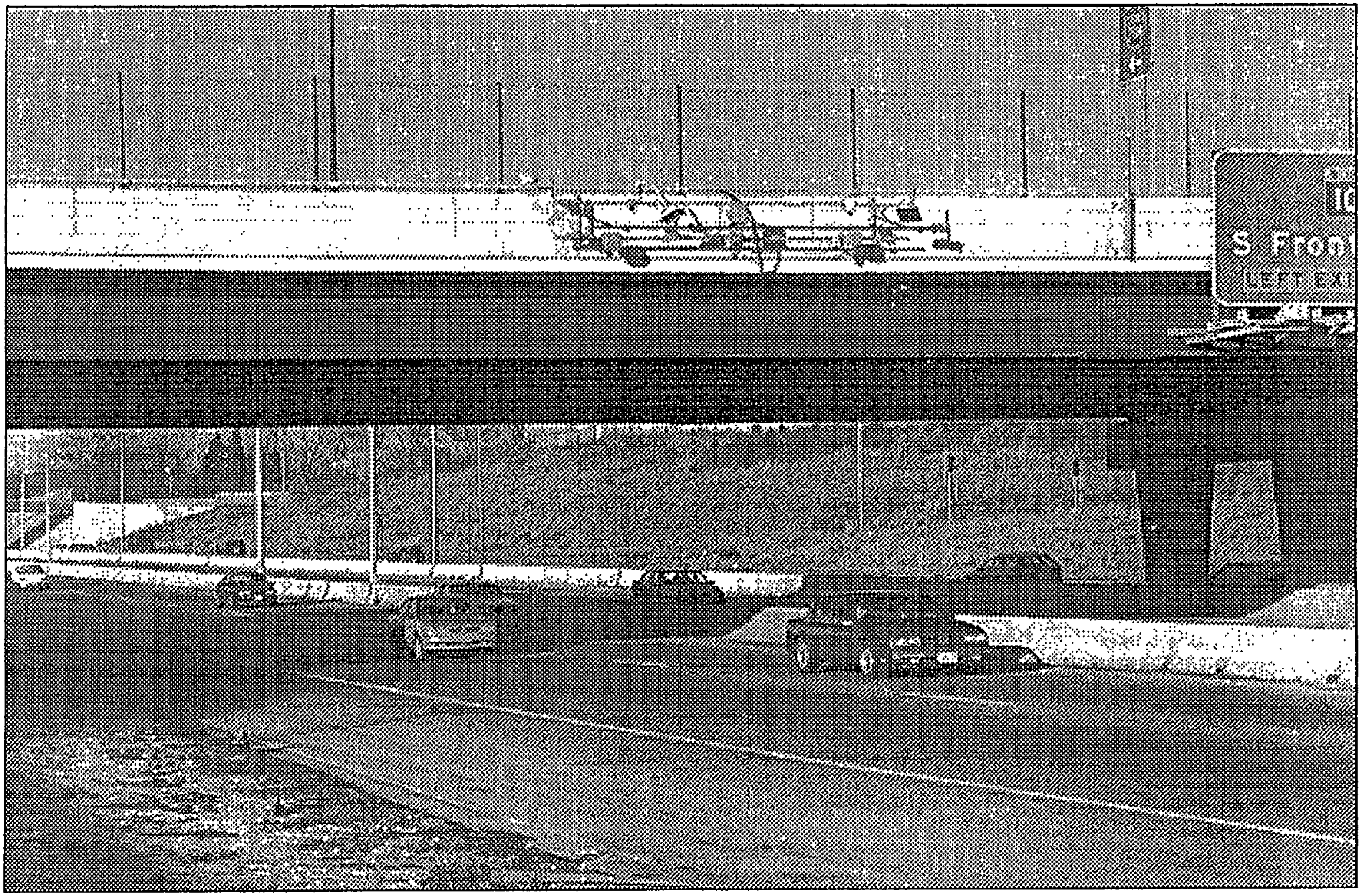
Table 2 Devices Evaluated in Phase I

Technolosv	Vendor	Device
Passive Infrared	Eltec Instruments	Model 842 Sensor*
Passive Magnetic	Safetran Traffic Systems	‘232E IVHS Sensor
Radar	Electronic Integrated Systems	RTMS
Doppler Microwave	Microwave Sensors	TC 26B*
Doppler Microwave	PEEK Traffic	PODD
Doppler Microwave	Whelen Engineering	TDW 10’
Doppler Microwave	Whelen Engineering	TDN 30
Passive Acoustic	AT&T	SmartSonic™
Pulse Ultrasonic	Microwave Sensors	TC 30C
Tripline Video	Rockwell International	TraffiCam™

‘These devices are not intended for the single-lane freeway monitoring configuration set up in Phase 1. Their performance was not compared to that of other detectors.

Table 3 Additional Devices to be Evaluated in Phase II

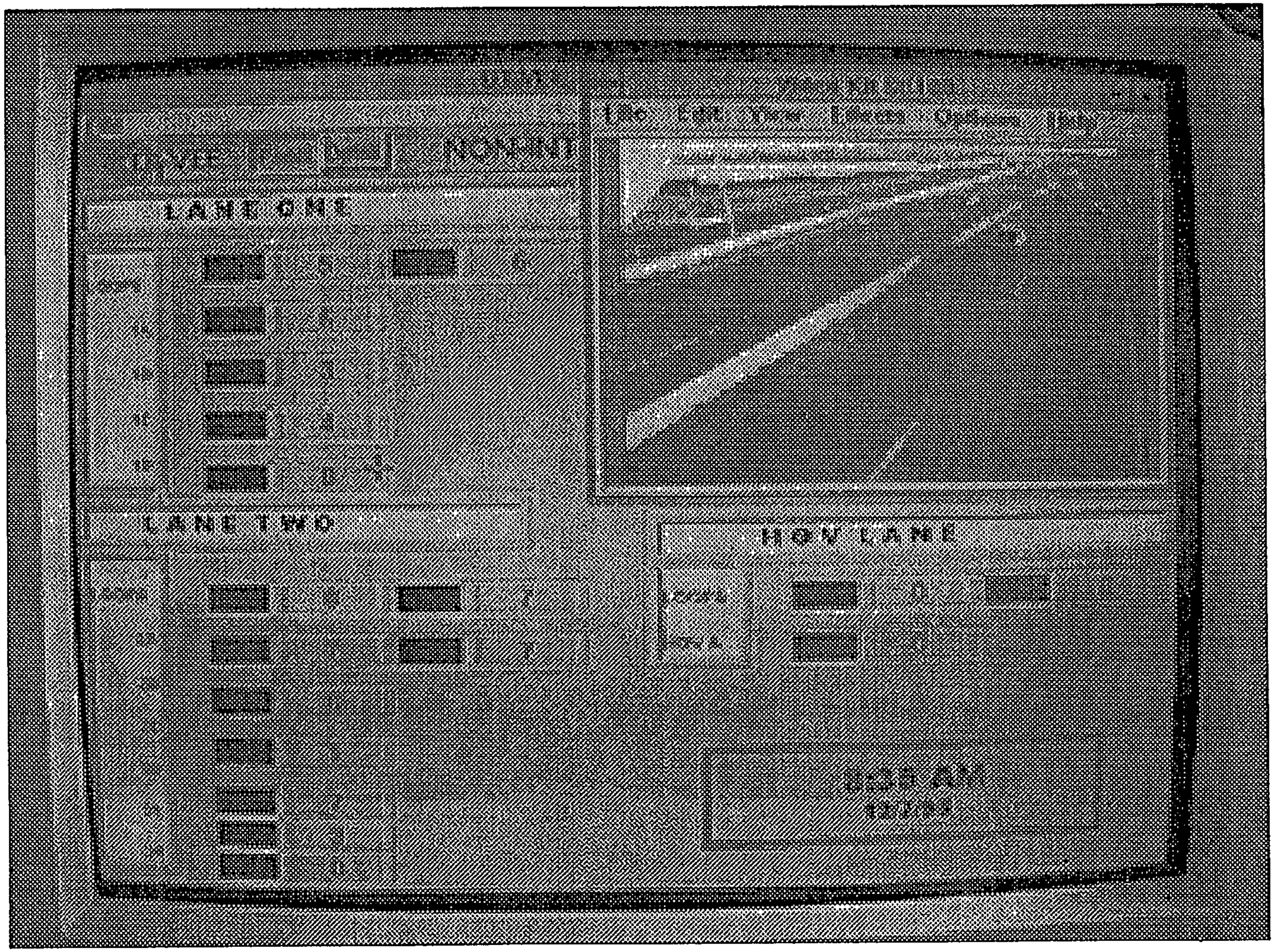
Technology	Vendor	Device
Passive Infrared	Eltec Instruments	Model 833 Sensor
Tracking Video	EVA, Inc.	2000 L
Tracking Video	PEEK Traffic Transyt	VideoTrak-900TM
Active infrared	Schwartz Electra-Optics	Auto Sense I
Passive Infrared	ASIM Engineering	IR-222
Tripline Video	Econolite	Autoscope 2004



Minnesota
Department of
Transportation

SRF NO. 0942006

FIGURE 1
INITIAL FIELD TEST SITE: I-394 AT PENN AVENUE
Field Test of Non-Intrusive Traffic Detection Technologies

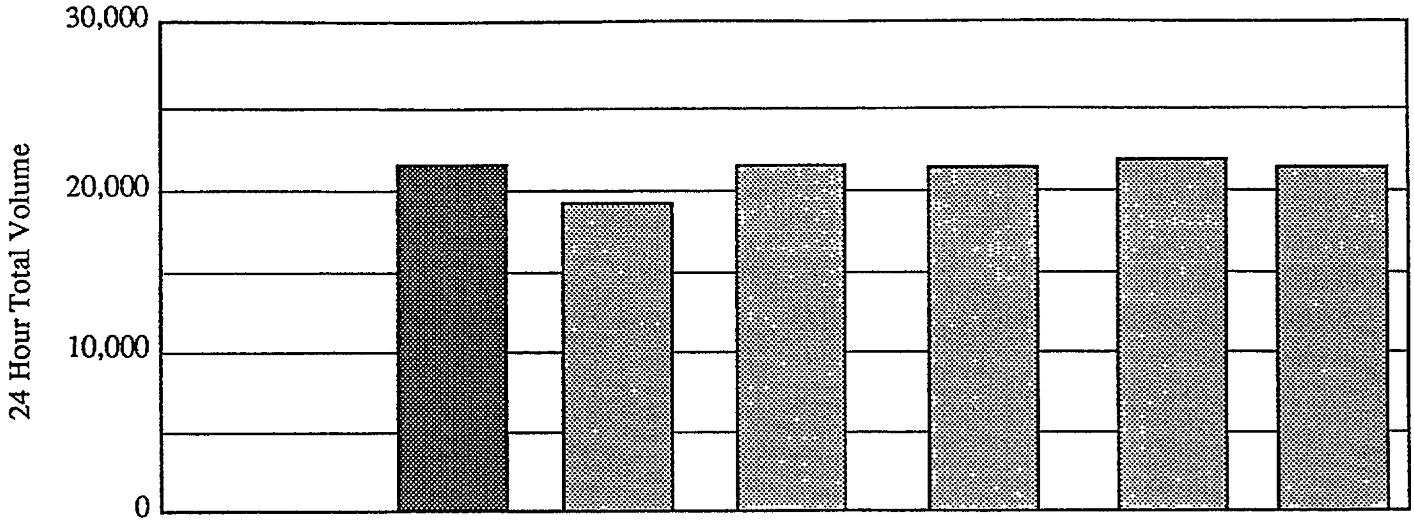


Minnesota
Department of
Transportation

SRF NO. 0942006

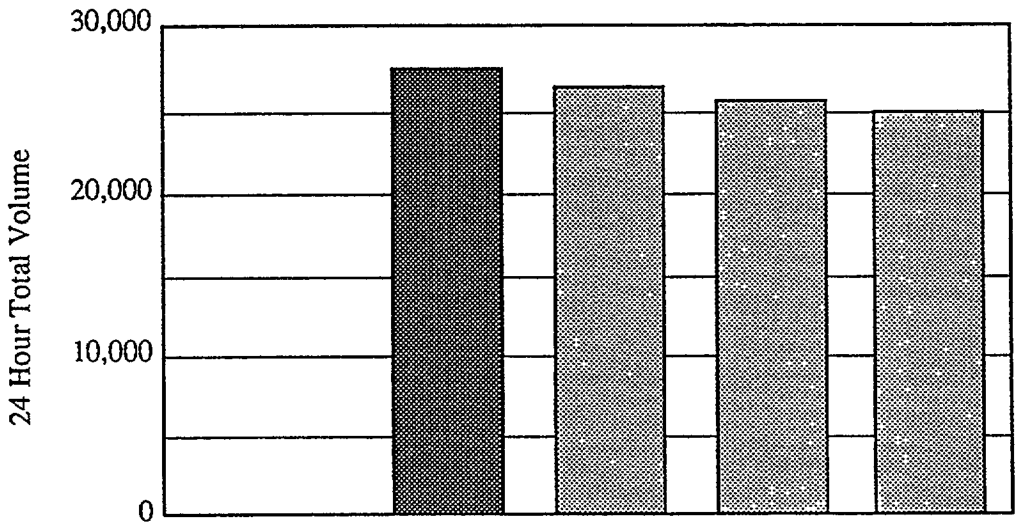
FIGURE 2
DATA ACQUISITION SOFTWARE
Field Test of Non-Intrusive Traffic Detection Technologies

LANE ONE



Technology	Baseline Loops	Passive Acoustic A	Pulse Ultrasonic	Doppler Microwave A	Doppler Microwave B	Tripline Video
Total Volume	21,392	19,171	21,468	21,234	21,770	21,416
Percent Difference (1)		-10.4%	0.4%	-0.7%	1.8%	0.1%
Correlation Coefficient (1)		0.9648	0.9997	0.9997	0.9991	0.7813 (2)

LANE TWO



Technology	Baseline Loops	Passive Magnetic	Radar	Passive Acoustic B
Total Volume	27,483	26,171	25,545	24,860
Percent Difference (1)		-4.8%	-7.1%	-9.5%
Correlation Coefficient (1)		0.9366	0.9904	0.9736

Notes:
1) Percent difference and correlation coefficient computed between device and baseline loops.
2) One hour time intervals used for tripline video data computation, all other results based on 5-minute intervals.

Minnesota Department of Transportation

SRF NO. 0942006

FIGURE 3

24 HOUR TEST RESULTS - JANUARY 19, 1996

Field Test of Non-Intrusive Traffic Detection Technologies

COUNTING TRAFFIC WITH INFRARED SENSORS IN FIFTEEN SIDE-BY-SIDE FREEWAY LANES

Clyde E. Lee
University of Texas at Austin

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

COUNTING TRAFFIC WITH INFRARED SENSORS
IN FIFTEEN SIDE-BY-SIDE FREEWAY LANES

by
Clyde E. Lee

RESTORATION OF A CONTINUOUS COUNTING STATION

For many years, the Texas Department of Transportation (TxDOT) operated a continuous vehicle counting station (an inductance loop detector in each lane) at a l0-lane freeway site on U.S. 59 about 15 km southwest of downtown Houston. This station became inoperable during a recent reconstruction project which included expanding a segment of the l0-lane freeway to a 12-lane freeway and replacing the existing median with a reverse-flow, high-occupancy-vehicle (HOV) lane where buses and other vehicles with two (three in peak periods) or more occupants travel between concrete traffic barriers. The new freeway cross-section also includes auxiliary lanes for entrance and exit ramp terminals. At the location of the previously-operated traffic counting station where an auxiliary lane is now provided on both sides, a stretch of Houston's Southwest Freeway comprises fifteen side-by-side lanes – an unusual, if not a unique, number and arrangement of traffic lanes.

Inductance Loop Detectors

To restore the long-established traffic counting station, TxDOT planned to install an inductance loop detector in each freeway lane – plus a pair of loops in the HOV lane to obtain the desired directional vehicle counts – and route the lead wires to the roadside in grooves sawn into the continuously-reinforced concrete pavement. There was some uncertainty about the reliability and maintainability of such a large number of adjacent loops with very long leads as no previous experience of this kind was known. Consideration was also given to the structural damage that would be inflicted upon the pavement, but the major concern was the hazard, time, and cost of sawing the abrasive-aggregate concrete pavements to accommodate the loop wires while working under traffic. TxDOT policy in Houston allows closing freeway lanes – with elaborate traffic-control procedures – only on Saturday and Sunday nights. Loop installation was expected to require at least five weekends. Clearly, an alternative vehicle sensor technology which did not require pavement sawing was needed for this site.

Infrared Light-Beam Vehicle Sensors

An ongoing cooperative research project between TxDOT and the Center for Transportation Research (CTR) at The University of Texas at Austin had recently demonstrated the practicability of using modulated infrared light-beam sensors for counting vehicles on interchange ramps. To respond to the immediate and important need for restoring the continuous counting station, the programmed research project objectives were rescheduled and modified to include adapting the successful vehicle sensing and counting technology to multi-lane freeways in lieu of loops.

INFRARED LIGHT-BEAM TECHNOLOGY

The advent of modem photoelectric sensing applications dates from the 1960's when photojunction devices, including the light-emitting diode (LED) light ***source*** and the phototransistor light receiver element, were introduced. (1) The operating characteristics of these devices make it possible to switch the source on and off very rapidly in a coded time pattern; this is called *modulation.* The receiver unit can be “tuned” to process only the coded pattern of modulated infrared light generated by the source and disregard other received light in the infrared spectrum, such as that in sunlight.

Source

Light-emitting diodes made from materials such as gallium arsenide and operating in the infrared (invisible) spectrum (about 850 to 950 mm wavelength, just above visible red) are the most efficient light sources. LEDs which operate in the visible spectrum (red, green, etc.) have been available since about 1975, but infrared light-emitting diodes are more powerful and are, therefore, more widely used. The infrared wavelength source was chosen for the Houston project.

Receiver

Photocells, photodiodes, phototransisitors and photodarlingtons can all be used as light *receivers,* but the phototransisitor has usually been paired with the infrared LED source for most applications as it has good light-receiving sensitivity and adequate speed of response for normal commercial sensing operations.

Lens

A lens is used in front of the source and the receiver to direct light within a narrow conical pattern – nominally 1 to 2 degrees in extent. The type of lens, of course, determines the zone of effectiveness for the source-receiver pair. The field of view of the reflex units selected for application in the subject project is 100 mm at 3 m. The maximum range of these commercially-available units is stated as 15 m when a conventional 76 mm diameter cube comer retroreflector is used. (2)

Thru-beam Mode

Maximum range of focused infrared light beam sensors is achieved when the source and the receiver are aligned directly opposite each other along the optical axis of both lenses. Operation of this arrangement requires that an electrical cable from the source and from the receiver be connected to a common signal controller unit. Very-long-range, thru-beam commercial products state effective distances up to 225 m. (2)

Reflex Mode

In the reflex mode of operation, a light source and a light receiver are both mounted behind adjacent, collimated lenses in the same housing. A retroreflector is placed across the detection zone opposite the source-receiver unit and aligned within the field of view of the lenses to return the transmitted, modulated light from the source back to the receiver. When an opaque object blocks the modulated infrared-frequency light beam which is emitted by the source, bounced back from the retroreflector, and normally detected by the receiver, an electronic switch is closed to indicate the presence of the object. An obvious advantage of this mode is that no electrical cable is required across the detection zone. Primarily, for this reason, the reflex mode of operation was chosen for application at the 15-lane freeway traffic counting site in Houston.

HOUSTON’S 15LANE FREEWAY SITE

At the 15-lane site described above, a 73 m-long overhead sign bridge structure clear-spans all traffic lanes, shoulders, and the New Jersey-shape concrete traffic barriers beside the shoulders. Freeway guide signs are mounted on the upstream side of the structure facing traffic in each direction, and luminaries are suspended about 2 m in front of, and slightly below, the lower chord of the bridge to light the signs at night. A 0.6 m-wide walk is provided between the luminaries and the signs for maintenance personnel to service the signs and lighting fixtures. The walk is about 6.7 m vertically above the road surface. A sketch of the cross-section arrangement is shown in Fig 1. The HOV lane is 6 m wide between barriers, each traffic lane is 3.6 m wide, and all shoulders beside the traffic lanes are 3 m wide. A traffic signal controller cabinet is attached to the bridge support columns adjacent to the northbound lanes to accommodate a 110 VAC electric power connection, a telephone line, and the traffic count recorders.

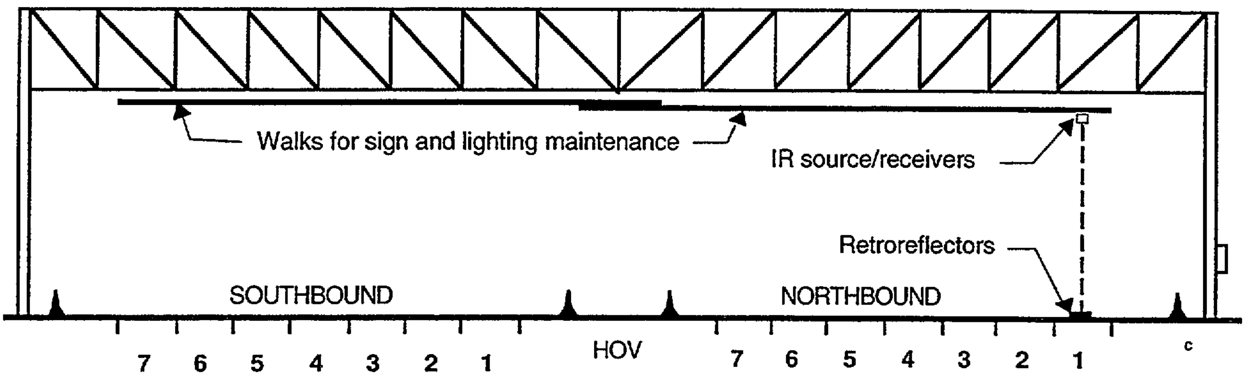


Fig 1. Sensor arrangement on 73 m-long sign bridge over fifteen traffic lanes.

INFRARED LIGHT-BEAM SENSOR ARRANGEMENT

Commercial reflex-type infrared light-beam sensors, which have a light source and a light receiver mounted behind adjacent lenses in the same housing (2), were selected for this project. Two sensor units, each housed in a stainless steel protective box that is attached to an aluminum beam, were clamped beneath the walk with U-bolts directly over the center of each traffic lane so that the two light beams were exactly 1 m apart (parallel to traffic direction) and pointed vertically downward. A screw-adjustable aiming device was developed to facilitate aligning the axis of each light beam accurately to the center of a special retroreflector cemented to the road surface in the traffic lane below.

The retroreflector comprises a grooved 150 x 200 x 6 mm aluminum plate, ramped at the leading and trailing edges, with encapsulated, reflective sheeting (3) adhered to the bottom of each groove. An enlarged longitudinal section through one end of the plate is shown in Fig 2. The principle of operation is that a tire which strikes the thin plate will be ramped upward and supported on the ridges so that it does not contact the sheeting in the bottom of the groove. Water will drain out the open ends of the grooves due to the normal cross slope of the road surface. Evaluation of three different cements during a three-month period, when various size plates were placed (intentionally) in the wheel path of an Austin freeway lane, indicated that the most durable material for attaching the plates to the pavement surface is the filled (mineral filler), air-blown asphalt cement which has come into popular use recently for attaching raised pavement markers. A small quantity of the asphalt cement is melted in an iron pot on-site with a gas torch and poured onto a pre-heated spot on the road surface. The pre-coated (with asphalt before the reflective sheeting is applied) plate is then positioned on the liquid asphalt cement. After about two or three minutes, the cement cools to near-ambient temperature and solidifies, and the retroreflector is ready for traffic use.

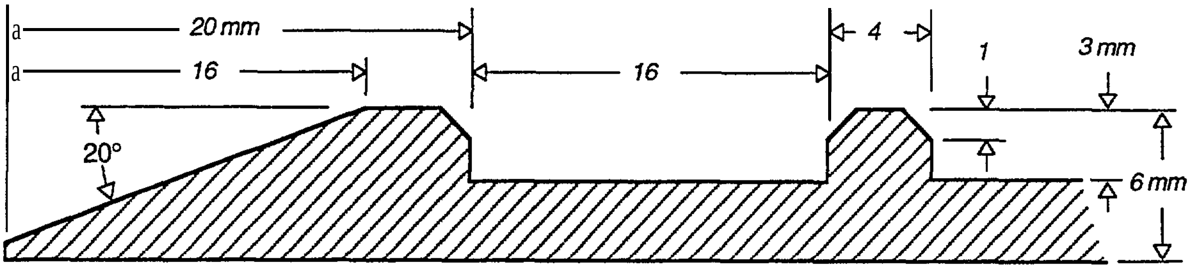


Fig 2. Section through aluminum retroreflector plate.

Only one sensor is needed to count vehicles in each one-direction traffic lane; however, two were installed. The reason for this was twofold: 1. The redundant sensor can be activated if a reflector is lost or the active sensor fails. 2. With appropriate processing of the signals from the two sensors, direction of travel, speed, vehicle length, and time headway of vehicle pairs can be calculated. Both sensors in the HOV lane are now being used to obtain directional counts in the reverse-flow lane. Signals from the two sensors are interpreted on-site in real-time by a microcontroller to determine the direction of travel, and then the vehicle-present signal is sent to the appropriate directional count recorder. The additional cost of providing two sensors instead of one in the other traffic lanes as part of the initial installation was considered to be relatively minor compared to the high cost of traffic control and the hazard to personnel that are associated with repair or expansion of the sensor array.

Each sensor requires a 3-conductor, shielded electrical cable between it and the roadside cabinet. A pair of conductors transmits 12 VDC (nominal) power and the third wire carries the output signal. Rigid metal electrical conduit (50 mm) was run on the bottom beams of the sign bridge and down to a cabinet near ground level to house the 30 sensor cables. Junction boxes were installed in the conduit over each traffic lane, and flexible conduit (19 mm) was used to run between the pairs of sensors and the junction boxes.

SIGNAL FILTER

The infrared light beam responds nearly instantly (1 or 3 ms) to blockage by an opaque object and reestablishes itself almost as rapidly. If there is an opening in a moving vehicle through which the narrow beam can pass, a change-of-state (switch open or close) occurs in the sensor output. This can result in an erroneous vehicle count. Similarly, in the reflex mode of operation, reflections of the beam from nearby, bright objects on the vehicle can reestablish the beam and give false vehicle counts. To alleviate these relatively-rare occurrences, Liren Huang, an electrical engineer at the Center for Transportation Research, designed a digital filter and programmed it onto a microprocessor which is inserted between the infrared sensor and the vehicle count recorder. In effect, the filter integrates all time pulses that are less than about 250 ms duration into a single pulse, which represents the time that a vehicle occupied the light beam. Thus pairs of vehicles traveling with a time-spacing (gap) greater than 250 ms will be sensed as individual vehicles.

INSTALLATION

The sensors and associated mounting hardware, including the special retroreflectors, were designed, procured, and fabricated at CTR during October and November 1994. Electrical conduit, fittings, and cable were furnished and installed by experienced personnel from the Transportation Planning & Programming (TP&P) Division of TxDOT, headquartered in Austin. Traffic control, bucket trucks, and sign-maintenance personnel to assist in installing the conduit and cable were provided by the Houston District.

Houston District operating policy allows closing freeway traffic lanes – only with approved procedures – on Saturday and Sunday nights, from 9:00 PM until dawn. All lanes below must be closed to traffic when personnel are working overhead. This meant that sensor installation had to progress from the roadside (with no return unless traffic was blocked again) toward the HOV lane in the median. The HOV lane is closed to traffic on weekends with gates and barriers at all access points; therefore, work could be done over this lane without special traffic control.

Installation began in the northbound lanes on Saturday night 19 November 1994 and continued again on Sunday night. Mounting sensors and conduit over the three blocked, outside lanes went smoothly and the 6 cables between the sensors and the roadside cabinet were pulled before midnight on Saturday. Work was resumed at about 2:00 AM on Sunday morning after the elaborate array of traffic control devices, including trucks equipped with energy attenuators for each blocked lane, was moved to open the three outside lanes and close the four lanes adjacent to the HOV lane. Again, installation of conduit and sensors went smoothly, but pulling the bundle of 32 cables from the roadside through the 50 mm conduit caused problems, and work stopped without completing the electrical connections for the sensors over these four lanes. The same four lanes were blocked again Sunday night, and the cable connections were completed before dawn. A different strategy for pulling the large number of cables of different lengths was needed.

Such a strategy was devised by Willard Peavy and Alan Grohman at TP&P Division in Austin during the next two weeks, and the installation of sensors in the seven southbound lanes and in the HOV lane was successfully completed on Saturday and Sunday nights 10 and 11 December 1994 before dawn on Monday. The need for adequate traffic control was clearly demonstrated, however, about 2:00 AM Sunday morning when a drunk driver sideswiped one of the energy-attenuator vehicles without causing major damage. Final roadside wiring and counter connections were made on Monday morning, and traffic counting in the fifteen side-by-side freeway lanes in Houston began at noon 12 December 1994. With the new cable-pulling strategy, it is felt that another similar installation can be completed in only one weekend.

OPERATION

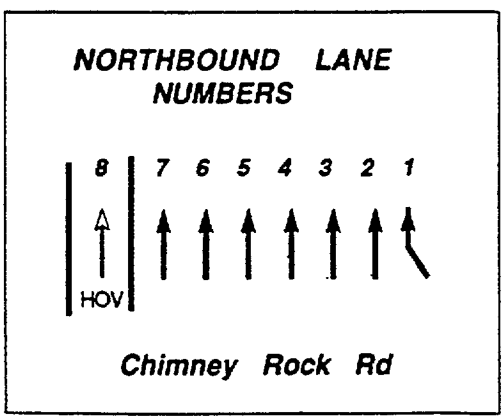
The restored continuous vehicle counting station, S-140, has produced traffic count data virtually without interruption during the past 14 months. Data from the two on-site count recorders, one for each direction of traffic, are transferred via modem to the TP&P Division data base in Austin via phone line modem on a routine basis where performance of the field equipment is carefully monitored. An example of the vehicle count data for Friday May 12, 1995 is shown in Figs 3 and 4.

Project 2043 TEXAS DEPARTMENT OF TRANSPORTATION ***NORTHBOUND***
AUTOMATIC TRAFFIC RECORDER REPORT
06-14-1995 Volume by Lane Report - D0512087.PRN 13:17 Pg 1

Sta: 000000000140 Id: 000000001188 CId: 01 Fmt: 010 Int: 60 Min
Start: Fri - May 12, 1995 at 00:00 End: Fri - May 12, 1995 at 24:00
City/Town: HOUSTON County: HARRIS
Location: US 59 0.6 MILES SOUTH OF IH 610 File: D0512087.PRN
Ln1-North Ln2-North Ln3-North Ln4-North Ln5-North Ln6-North Ln7-North Ln8-North

Fri - May 12, 1995

Lane	1	2	3	4	5	6	7	8	Total
01:00	187	275	360	314	299	209	367	0	2011
02:00	119	164	251	204	196	147	227	0	1308
03:00	100	215	268	203	172	127	207	0	1292
04:00	65	106	168	150	134	87	128	0	836
05:00	77	148	235	175	186	173	136	1	1131
06:00	308	342	764	495	524	601	215	19	3268
07:00	1080	851	1357	1096	1535	1731	632	295	8577
08:00	1523	1088	1266	1591	2103	2272	1002	1304	12149
09:00	1317	1052	1350	1444	1615	1665	1028	603	10074
10:00	974	970	1474	1147	1422	1542	889	115	8533
11:00	903	965	1518	1134	1428	1519	1052	40	8559
12:00	1099	946	1451	1001	1352	1471	1242	27	8589
13:00	1175	903	1542	1129	1510	1563	1310	6	9138
14:00	1090	1000	1496	1164	1512	1601	1284	1	9148
15:00	1214	977	1321	1059	1462	1668	1404	0	9105
16:00	1008	853	977	1019	1424	1666	1650	1	8598
17:00	810	809	754	1026	1474	1783	1782	0	8438
18:00	921	803	1191	1081	1479	1648	1772	6	8901
19:00	779	802	1371	1159	1453	1655	1473	0	8692
20:00	927	866	1414	1027	1268	1312	1190	0	8004
21:00	655	788	1105	876	905	920	1018	0	6267
22:00	655	720	1060	875	845	862	970	0	5987
23:00	532	657	926	809	802	781	965	0	5472
24:00	431	493	741	637	641	538	833	0	4314
Daily Totals	17949	16793	24360	20815	25741	27541	22776	2418	158393



(Friday May 12, 1995)

NORTHBOUND	***158,393***
(Southbound	170,293)
TOTAL, vehicles per day	**328,686**

Fig 3. Example of vehicle counts for northbound traffic at S-140 in Houston

Project 2043 **SOUTHBOUND**

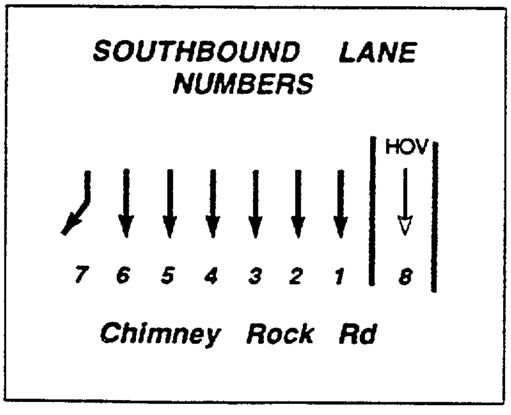
TEXAS DEPARTMENT OF TRANSPORTATION
AUTOMATIC TRAFFIC RECORDER REPORT

06-14-1995 Volume by Lane Report - D0512088.PRN 13:17 Pg 1

Sta: 000000000140 Id: 000000001188 Cld: 02 Fmt: 000 Int: 60 Min.
Start: Fri - May 12, 1995 at 00:00 End: Fri - May 12, 1995 at 24:00
City/Town: HOUSTON County: HARRIS
Location: US 59 0.6 MILES SOUTH OF IH 610 File: D0512088.PRN
Ln1-South Ln2-South Ln3-South Ln4-South Ln5-South Ln6-South Ln7-South Ln8-South

Fri - May 12, 1995

Lane	1	2	3	4	5	6	7	8	Total
01:00	388	170	58	349	520	662	195	0	2342
02:00	217	83	46	227	263	366	129	0	1331
03:00	202	69	22	194	246	318	130	0	1181
04:00	124	33	13	107	144	187	63	0	671
05:00	133	47	57	122	132	166	44	1	702
06:00	262	139	386	226	300	417	116	1	1847
07:00	699	548	1862	714	922	1100	306	2	6153
08:00	1039	841	2435	1050	1339	1801	513	5	9022
09:00	986	769	1711	1066	1396	1748	581	1	8258
10:00	885	681	1505	1000	1286	1504	538	0	7399
11:00	1017	777	1367	1126	1431	1614	600	0	7932
12:00	1234	1069	1343	1306	1518	1769	673	0	8912
13:00	1275	1151	1363	1324	1644	1881	776	1	9415
14:00	1312	1191	1478	1355	1667	1799	712	0	9514
15:00	1418	1378	1724	1467	1664	1930	704	91	10376
16:00	1720	1936	1833	1600	1742	2058	742	229	11860
17:00	1911	2135	2022	1758	1777	2261	704	584	13152
18:00	1857	2083	1776	1775	1901	2325	625	977	13319
19:00	1530	1569	1722	1450	1656	2086	586	391	10990
20:00	1199	1123	1136	1263	1554	1793	573	149	8790
21:00	1044	934	647	1092	1347	1629	531	44	7268
22:00	1002	848	564	1036	1371	1637	583	0	7041
23:00	1063	849	534	1105	1498	1595	537	0	7181
24:00	817	642	300	869	1151	1384	474	0	5637
Daily Totals	23333	21065	25904	23581	28469	34030	11435	2476	170293



(Friday May 12, 1995)

SOUTHBOUND	***170,293***
(Northbound	158,393)
TOTAL, vehicles per day	**328,686**

Fig 4. Example of vehicle counts for southbound traffic at S-140 in Houston

The hourly count in each lane is tabulated. Lane 8 indicates the directional count in the HOV lane. There are obvious errors in these directional counts. It is not possible to have several vehicles operating in the opposite direction to several hundred others within the same hour. It is possible, however, to have a wrecker or a service vehicle travel in the opposite direction during the hours when the flow direction is being reversed. No explanation for the directional sensing error is offered except to point out that an error might occur when a vehicle passes partially over one reflector and not the other while the vehicle is moving laterally in the lane. The reflector is centered in the 6 m-wide lane; a small passenger car is about 1.7 m wide. Spurious reflections can be generated from the tops of buses that are in close proximity to the overhead sensor and also possibly cause errors in directional sensing. Because of these inconsistencies, reflex type sensors in the overhead configuration are not recommended for wrong-way-movement detection. They are, however, considered quite adequate for acquiring statistical count data. Thru-beam infrared light-beam sensors have proved to be virtually error free in detecting vehicles by direction of movement in Houston's HOV lanes (see Ref 4).

Since the system was commissioned 14 months ago, eight reflectors have been dislocated. Six of these have been found on the shoulder of the road. Examination of the recovered reflectors reveals that some heavy metal object dragged by a moving vehicle struck the leading edge of the aluminum plate with sufficient force to shear the bond between the bottom surface of the plate and the asphalt cement adhered to the portland cement concrete pavement surface. Deep gouges are found in the aluminum, and in some cases scrape marks can be seen on the concrete pavement surface. After about ten months of operation, both reflectors in the auxiliary lane which serves the southbound exit ramp to Chimney Rock Road were lost at the same time. It was not possible to count traffic in this lane without a reflector. A few days later, while working beyond approved traffic-control and crash-cushion vehicles, TxDOT personnel melted the asphalt cement remaining on the pavement surface with a gas torch and installed two new reflectors in less than five minutes. One of these replaced reflectors was scraped loose again last week – some four months later, but counting continues while using the other reflector that is still in place. In all cases in which only one reflector has been lost, it has been possible to continue counting by using the remaining sensor-reflector unit. No sensor has lost its alignment. Heavy rain or fog does not seem to have any adverse effect on the performance of the sensors. The experience described above, with reflectors being scraped from the road surface, points out a limitation of using this type retroreflector where snow plows operate.

COST

The cost of the commercially-available reflex infrared light-beam sensors, bought retail in small quantity, was approximately $130 each. The cost of materials and fabrication of the sensor mounting and signal conditioning hardware was about $250 for each 2-sensor unit, and each retroreflector cost about $30, as it was machined from aluminum plate stock. The per-lane installed cost of cable and conduit varied with the length of run to the cabinet. Traffic control was contracted at about $15,000 per weekend, and the installation was completed in two weekends. Maintenance costs have been minimal during the first year of operation. These seem to be quite favorable costs for sensing vehicles in multiple freeway lanes when compared with the alternative of installing and maintaining inductance loop detectors.

SUMMARY

To count traffic on a 15-lane section of Houston freeway without cutting the continuously-reinforced concrete pavement, reflex-type infrared light-beam sensors were mounted on an overhead sign bridge structure and aimed at retroreflectors cemented on the pavement in the center of each lane below. When a vehicle blocks the modulated (switched on and off in a coded time pattern) infrared-frequency light beam which is emitted by the source, bounced back from a special low-profile retro-reflector cemented on the surface of the lane below, and detected by the receiver, an electronic switch is closed to indicate the presence of the vehicle. Two sensor/reflector units were installed for each lane during two weekends – without intruding the pavement – and made operational in December 1994. During the past 14 months, daily vehicle counts have been as high as 328,000 and the system has operated virtually continuously for all lanes except for a few hours after reflectors were dislocated. Two reflectors were scraped from the pavement in the auxiliary exit ramp lane by some heavy metal object dragged by a moving vehicle. TxDOT personnel melted the asphalt cement remaining on the pavement with a gas torch and installed new reflectors in less than five minutes while working beyond approved traffic-control and crash-cushion vehicles. Where overhead structures are available for mounting the sensors and snow plows do not operate, this system offers an attractive alternative to inductance loop detectors.

ACKNOWLEDGMENTS

In addition to those already mentioned in the text, the contributions of several other individuals to the success of this project are recognized with appreciation. Deborah Morris and Dean Barrett supported the participation of TxDOT's TP&P Division in the research. Dayton Grumbles, TxDOT Project Director for the infrared sensor research study, encouraged the adaptation of the sensor system and personally assisted during the on-site installation in Houston. He has maintained a continuing interest in the performance of the system during the past months. Robert F. Inman, Research Engineer Associate at CTR, designed much of the mounting hardware, supervised its fabrication, and assisted in the installation. Michael T. De Vries and Ramanathan P. Subramaniam, Graduate Research Assistants at CTR, participated in the fabrication, installation, and evaluation of the sensor/retroreflector units.

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SMARTSONIC SENSOR SELECTION: PRO'S AND CON'S

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Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

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SMARTSONIC SENSOR SELECTION: PRO'S AND CON'S

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ARIZONA DEPARTMENT OF TRANSPORTATION

Arizona Department of Transportation (ADOT) faced a complex problem, the need to gather massive amounts of data from hundreds of in-ground loop monitoring stations. Problems with in-ground loops forced ADOT to consider alternatives. Costs for freeway closures, due to in-ground loop repair and replacement, were steadily climbing Alternate methods, such as Passive Acoustic Detectors and Video Imaging, were considered. Due to unit cost and installation, Passive Acoustic Detectors (PAD's) were selected to be tested against in-ground loops.

During testing, 12 PAD's were installed at a test location with heavy East and West traffic. Temporary in-ground loops were also installed. The testing process continued for about 180 days or until in-ground loop failure. Vehicle spread traffic volume and lane occupancy percent data was compared. The data between PAD's and in-ground loops differed on three to five percent. As a result of these tests, the Passive Acoustic Detectors are being installed at over 30 locations instead of in-ground loops.

CONCURRENT SESSION 5A - NEW APPROACHES

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

A MODEL FOR INFORMATION INTEGRATION WITHIN TRANSPORTATION AGENCIES

William R. Youngblood
Georgia Tech Research Institute

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

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A MODEL FOR INFORMATION INTEGRATION WITHIN TRANSPORTATION AGENCIES

William R. Youngblood, Georgia Tech Research Institute (GTRI),
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1. ABSTRACT

This paper summarizes the generic results of an FHWA and GDOT sponsored research project to develop a model process for integrating transportation information processes within and between transportation agencies at various jurisdictional levels. It is anticipated that these results will of interest to all States.

First, the project is described in terms of standard project parameters (schedule, individuals involved, etc), research objectives, and technical approach.

Next, the paper reports the situation within representative (hopefully) transportation agencies with respect to information processes. This phase of the project addressed functions performed, information needs, existing information practices, and observed information integration opportunities.

The information integration model is then presented. The basic logic behind the information integration concept is introduced. Minimal requirements for integration are identified as transportation information standards, and a standard integrated database in all agencies. In its broadest scope, the integration concept is a standardized and fully integrated Transportation Information System (TIS).

Finally, specific activities to implement the integrated information model are recommended, in priority sequence.

2. PROJECT OVERVIEW

The project, its objectives, and the technical approach are described.

2.1 Project Description. The title, researchers involved, the FHWA and GDOT project staffs, and the performance period are as shown in Table 1. The project is being performed by the Georgia Tech Research Institute, with significant participation by many members of the GDOT staff. The project focuses on the traffic data processes within the GDOT, Atlanta Regional Commission (ARC, The Metropolitan Planning Organization (MPO)), and City of Atlanta (COA).

After the initial task of this project was completed, GDOT decided to develop a comprehensive strategic plan for ail Department information systems. The author led both efforts, and the concepts reported herein represent a combination of relevant results from both projects.

2.2 Project Objectives. This research has the following three fundamental objectives:

- To develop and demonstrate a model process for integrating the collection, storage and sharing of “traffic” data within and between transportation agencies *at all jurisdictional* levels. Since it is difficult to use traffic data independently of other information about the transportation system, the model addresses information used in all functions of the transportation agencies.

Table 1. Project Information

Title:	Integration of Traffic Data Collection and Traffic Operations
Researchers:	Bill Youngblood, Ga Tech Project Director Wayne Sarasua, Ga Tech Civil Engineering Stefan Roth, Ga Tech Research Institute
Sponsors:	Federal Highway Administration and Georgia Department of Transportation FHWA Project Manager: Bill Grush GDOT Manager: Darrell Elwell GDOT Project Administrator: Rick Deaver
Dates:	August 1993 through December 1997 (as Extended to match ATMS schedule)

- To achieve the first objective in concert with the development of GDOT's Advanced Transportation Management System (ATMS). The ATMS will collect significant amounts of traffic data which will be useful for other transportation functions.
- To incorporate the ISTEA Management Systems (MSs) in the model process. These systems will be of most benefit as elements of *an* agency's *comprehensive* transportation management system, which must be based on *an integrated* information system.

2.3 Approach to This Research. The approach to this project is defined by its four tasks, designated A through D.

In Task A, all *major* traffic data collectors, users, and processors within the three participating agencies were interviewed. The objectives were to identify existing data collection activities, the uses to which data are applied, current data needs, and the degree to which these needs are being satisfied. An assessment was also made of future data needs and the degree to which current and planned data collection efforts would satisfy those needs.

In Task B, the objectives were to develop an integration concept that would provide synergistic collection and optimum sharing of data, and then to develop a demonstration of the concept. This task is completed except for the demonstration system, which must await completion of the Atlanta area ATMS.

The remaining tasks, C and D, require a one year test of the demonstration system, and to evaluate and report the benefits and lessons resulting from the demonstration.

In addition, to develop the strategic plan for GDOT information systems, all GDOT Division and Office managers and other senior staff were interviewed. With the knowledge gained, a more thorough analysis was conducted of all Department functions, necessary information processes, current information systems, and the potential for information systems to aid functional performance. A conceptual design for the future integrated GDOT information system was developed, along with a detailed implementation plan.

3. AGENCY INFORMATION PROCESSES

A rational information integration plan must be based on the information processes that exist within the agencies, which are determined by the functions performed. This discussion, then, identifies the functions performed, assesses the information needs involved, and then reports the information processes observed. Thereafter, the identified integration opportunities are discussed.

3.1 Transportation Agency Functions. Governments are expected to provide an effective transportation system to move people and goods. To provide such a system, the transportation agency must perform certain functions. The most basic of these functions are:

- Planning, which is responsible for monitoring current transportation system usage, identifying usage trends and existing or potential problem areas, and identifying the system changes necessary to accommodate observed needs, both present and future.
- Development, which designs and constructs new transportation system facilities and upgrades existing ones as needed.
- Operations, which oversees day-to-day operation of the transportation system to ensure that it is operating in a safe and efficient manner.
- Maintenance, which is responsible for keeping those transportation system components that the agency is responsible for in good operating condition.

Other major transportation agency functions for which information processes and systems must be considered are:

- Management, which provides the oversight and decision making to assure a sufficient and efficient transportation system.
- Support, which acquires and administers resources (staff, funds, facilities, equipment, supplies, etc.) needed to perform the agency's functions.
- Traffic Safetv, which includes all activities necessary to minimize the deaths, injuries and property damage due to accidents on the transportation system.
- Environmental Protection, which includes the activities of assessing enviromental impact prior to constructing a transportation facility and dealing with the pollution caused by vehicles operating on existing facilities.
- Intermodal Considerations, which fulfills the transportation agencies responsibilities for integrating the multiple transportation modes to form the most effective overall transportation system.

These functions were all considered in assessing the information processes of the transportation agencies.

3.2 Generic Information Needs for Agency Functions. This section provides the conceptual foundation for identifying information needs of transportation agencies. The concept of a transportation system (of which the road system is just one mode) is discussed, which is key to defining information needs and to organizing that information into a database. Using the system concept, generic types of information are identified to describe a transportation system and its usage (traffic).

3.2.1 The Tmnsportation System Concept - The overall transportation system consists of land, water, and air modes; with the land mode usually divided into road and rail modes. For some purposes the road mode is further divided; i.e., into walking (pedestrian), private vehicles, freight carriers, and passenger carrying vehicles (busses, etc.). Most of the modes are typically divided into passenger and freight components. The components of each mode are the users, activity centers, terminals, mode facilities, vehicles, and the environment. Each of these component categories has a different role in the transportation system, and has characteristics that must be understood by the transportation agency. Table 2 summarizes these classes of components and their roles in the transportation system, and the characteristics of interest will be defined in the next subsection.

Table 2. Transportation Mode Components and Roles

Component	Definition/Role
Users (includes goods)	Reason for transportation system's existence
Activity Centers	Laud areas where users live or to which they travel for desired activities; the origins and destinations of trips
Terminals	Junction nodes where users change modes
Mode Facilities	Provides routes and other en-route facilities between terminals
Vehicles	Transports users via mode routes
Environment	The context in which all other components exist

For the highway mode, which is of primary interest for this study and will be referred to as the road system, the component and subcomponent categories are identified in Table 3.

Table 3. Road System Components and Subcomponents

Users	Road Facilities	Terminals	Vehicles	Activity Centers	Environment
Drivers, Passengers, Fedestriaus, Goods	Sections, Bridges, Intersections, Control Devices, Etc.	Garages, Parking Lots, Bus Stops, Airports, Ports, Rail Terminals, Etc.	Cars, Trucks, Buses, Motorcycles, Bicycles, Etc.	Residential, Shopping, Employment, Recreation, Etc.	Polluted Areas, Sensitive Areas, Historical Sites, Protected Species, Etc.

3.2.2 Traffic Concepts

In the global sense, traffic is the movement of users between activity centers via one or more modes. Within each mode, traffic is the movement of users in vehicles over the routes that interconnect terminals. Road system traffic may be characterized by parameters that describe either the collective vehicle stream or the individual vehicles in the stream.

3.3 **Road System Traffic Data Needs and Types** Each and every one of the transportation agency functions requires information about the road system to perform effectively. Necessary information includes a representation of the system, characterizations of system components, and traffic movements within the system. Table 4 summarizes the needed road system and traffic

Table 4. Road System and Traffic Generic Information Needs

Component or Traffic	Subcomponents or Types of Data	Generic Data Items
Road System	All Components	A Map, Providing Identifiers of all Components and Objects of Interest, Spatial Parameters, Interconnectivity, Relationships, etc.
Roadway Facilities	Sections	Functional Class, Spatial Parameters, Engineering Data, Project History, Condition
	Bridges	Spatial Parameters, Engineering Data, Project History, Condition
	Intersections	Spatial Parameters
	Traffic Control Devices	Type of Device, Spatial Parameters, Engineering Data, History, Condition
	Appurtenances	Type Device, Spatial Parameters, Engineering Data, History, Condition
Users (Drivers and Passengers)	Categories, Distribution	Age, Sex, Health, Education, Income, etc.
	Physical Characteristics	Dimensions, Weight, etc.
	Performance Parameters	Sensing Distances, Reaction Times, Driving Skills, etc.
User (Goods)	Categories, Distribution	Raw Materials, Manufactured Goods, etc.
	Physical Characteristics	Dimensions, Weight, Volume, State (Solid, Liquid, Gas), etc.
	Hazard Characteristics	Benign, explosive, radioactive, toxic, etc.
Vehicles	Types and Distribution	Passenger Cars, Heavy Trucks, Motorcycles, etc.
	Physical Characteristics	Length, Height, Width, Weight, etc.
	Performance Parameters	Acceleration, Braking, Steering, etc.
Terminals	Categories	Modes Interconnected
	Spatial parameters	Location, Geometries, Dimensions, etc.
	Performance Parameters	Throughput Capacities, User/Goods Categories Supported, etc.
Activity Centers	Nature of Use/Activity	Residence, Shopping, Recreation, Manufacturing, etc.
	Spatial Parameters	Location, Geometries, Dimensions, etc.
	Traffic Characteristics	Parking Capacity, Patronage, Seating Capacity, Modes Available, etc.
Traffic Generation Parameters	Users (Drivers and Passengers)	Individual and Aggregate Trip Data (Origins, Destinations, Mode Choices, In-Vehicle Occupancy or Ridership, etc.)
	Users (Goods)	Individual and Aggregate Trip Data (Origins, Destinations, Modes, Goods Type and Characteristics, etc.)
	Terminals	User/Goods Volumes, Temporal Distribution, Origins/Destinations, etc.
	Activity Centers	Trip Generation Statistics (Volume, Origins/ Destinations , Temporal Distribution, Mode Splits, etc)
Traffic Movement (Stream)	Roadway Sections	Volume, Speed, Density, Video, Capacity, Volume/Capacity Ratio, etc.
	Intersections	Movement Volumes, Approach Speeds, Level-of- Service, etc.
Traffic Movement (Vehicles)	Roadway Sections	Spacing, Travel Time, etc.
	Intersections	Delay, Stops, etc.
Accidents and Incidents	Individual Events and Cumulative Data	Location, Events, Circumstances, Causes, etc.

information. Note particularly that the system is united, both conceptually and from an information organization viewpoint, by a representation of the system; i.e., a map.

3.4 Observed Information Practices. Observed infornnation practices within the subject transportation agencies are discussed in terms of the information collected, current information sharing, the degree to which information needs are or will be satisfied, and the potential for sharing information between functions within agencies and between agencies.

3.4.1 Information Currently Collected - Of the three transportation agencies, ARC and COA collect information only as needed; i.e., there is little or no routine collection. GDOT routinely collects both road system and traffic information; including system inventory, sampled traffic (all functional classes of roads), facility condition (bridges, pavements, signs, signals, etc), sparsely sampled speed, truck monitoring, and intersection signal related traffic parameters. Extensive amounts of information are generated by the functions within each agency, and kept in paper or electronic files. Also, the Georgia Department of Public Safety (the State Highway Patrol) routinely collects accident data, which is of obvious interest to the transportation agencies.

3.4.2 Current Infomtion Sharing - Only GDOT's road system inventory, sampled traffic data, and accident information are routinely shared. These information types are in on-line databases which can be accessed by GDOT functions. External agencies have to request this information from GDOT. In all three agencies, most collected or generated information is stored away after its initial use, typically in paper or diskette form in physical files. In some cases, other functions within the agency, and particularly in other agencies, are not aware that this information exists. Even if aware of the information's existence, the barriers to sharing the information are not insignificant. The user must request the information, wait for the provider to respond, and then try to interpret and use the information for a purpose different from that for which it was collected. The provider must expend effort to retrieve, copy, forward, and then answer questions about the information.

3.4.3 The Degree to Which Data Needs are Satisfied - Most of the functions within the transportation agencies felt that they could obtain or derive the minimum information necessary to perform their functions. Many also felt that they needed more detailed and more accurate information to perform optimally now, and would definitely need better information in the future. Specific traffic information types that users expressed a desire for, and that are not currently available, are discussed hereafter by transportation function.

Planning (GDOT and **ARC**) - Both the GDOT and ARC planners clearly desired significantly more data, of several types, than is currently available to them. Both groups expressed a desire for both more extensive data and more current data. The types of data commonly desired were:

- Capacities, volume-to-capacity ratios and level-of-service values for both road sections and intersections. Planners currently must estimate these parameters themselves and obviously feel that the data would be more accurate if estimated in the field by traffic engineers,

- Intersection descriptions, including traffic control devices, signal timing, and movement volumes,
- Average speed or travel times for all significant roads,
- Extensive and current origin and destination data for the metropolitan areas, and
- In-vehicle occupancy data for the major roadways, especially in the metropolitan areas.

Planning (ARC Only) - The ARC also expressed a need for several types of data unique from the GDOT planners. These were:

- Peak volumes on the major roads in the metro area,
- Annual Average Daily Traffic (AADT) to a finer geographic grid, and
- Annual Vehicle Miles Traveled (AVMT.) to a finer geographic grid.

The ARC will also be responsible for evaluating and reporting the effectiveness of the High Occupancy Vehicle (HOV) lanes to be established on the Atlanta area freeways, the first of which began operation in December of 1994. An HOV evaluation plan has been developed that identifies the data needed, but the methods and responsibility for collecting this data are not yet completely decided. The information needed includes, for all lanes of the freeways during the hours of HOV operation:

- Volumes,
- In-vehicle occupancy,
- Travel times, and
- Accident and injury rates.

GDOT Road Designers - The road designers clearly desired more extensive data on percent of trucks in the traffic stream, and more accurate data on the weights of those trucks. Available vehicle classification data is from the State's sampling program, and therefore frequently does not covers the specific road being designed. The truck weight data in pavement design tables can only be as current as the tables, and represent averages rather than that of trucks that are or would use the specific road being designed.

Multimodal Programs - The Office of Multimodal Programs indicated a future need for data on the flow of commodities over the road system. This need will extend to other modes as well.

3.5 Specific Integration Opportunities Identified

There were several significant integration opportunities identified in the first task of this project. These opportunities represent information already being collected, or planned to be collected, for which other users expressed a strong need. Each of the most significant opportunities will be discussed in the following paragraphs. The ATMS represents the most beneficial opportunity and therefore was selected by GDOT for this project's demonstration.

3.51 Data That Will Be Collected Routinely in the Future by the ATMS

The Advanced Transportation Management System (ATMS) currently under development for the entire metropolitan Atlanta area will collect several types of data on all major area streets and highways for real-time traffic management purposes. The specific types of data that will be definitely be collected at a large number of locations on all freeways and major arterials are:

- Continuous volumes,
- Speed,
- Classification (four bins)
- Density of traffic (calculated),
- Congestion indexes (calculated), and
- Video coverage of the freeways.

An extensive amount of data for all major arterial intersections, including signal timing, sensor outputs, and engineering quality graphics/drawings, are also planned to be incorporated into the ATMS.

The ATMS project staff are also seriously considering a capability to capture travel time data, at least for some freeway and major arterials.

Depending on the technology chosen for travel time data collection, and the population of vehicles that can be used as "probes," it may also be possible to derive useful origin and destination data. The video of the freeways may also be useful for this purpose.

The ATMS information is of strong interest to GDOT and ARC planners, and should be of interest to the safety analysts and other functions.

3.52 HOVLane Monitoring Data - GDOT will begin operating HOV lanes on many of the Interstate highways within the Atlanta area in 1996. The HOV lanes on I-20 were opened in December of 1994. These HOV lanes must be monitored to determine their operational effectiveness. ARC has published an HOV Monitoring and Evaluation Plan, including a list of data needed to fulfill their responsibilities. GDOT, through the ATMS and other means will likely have or collect most of the needed information. The identified needs are for both before and after data for the peak hours in *all* freeway lanes on:

- Volumes,
- In-vehicle occupancy,
- Travel times, and
- Accident and injury rates.

3.5.3 Truck Monitoring - GDOT's Office of Permits and Enforcement is responsible for enforcing truck weight and size limitations on the State's roadways. In the process, they obviously check the weights of a very large number of trucks. This weight data could be useful to the road designers. Currently this truck weight data is not being used external to the enforcement function, and is kept for only a limited time. The weight data measured or collected is from:

- 19 permanent weigh stations on the interstate highways, which weigh all passing trucks,
- 6 semi-permanent sites, which weigh all passing trucks for 8-16 hours per day,
- 9 teams with semi-portable scales, which operate daily for 4-8 hours at changing locations, weighing all passing trucks, and
- 42 roving teams with portable scales that stop and weigh those trucks suspected of being overweight.

This information is of interest to the road designers, and potentially to the intermodal planners and safety analysts as well.

3.5.4 Intersection Information - GDOT's Office of Traffic Operations is responsible for all traffic signals on the State Highway System, even though local governments are given direct control where possible. The Department currently checks each intersection with a traffic signal under its control about once per year. Although the data collected during these checks have long been maintained in the district offices, GDOT traffic engineers have recently begun to standardized the content of these data files. The plan is to record intersection diagrams, traffic movement data and signal timing information.

This information is of strong interest to GDOT and ARC planners, and should be of interest to the safety analysts and other functions.

4.0 THE INTEGRATION CONCEPT FOR TRANSPORTATION INFORMATION

Integration is defined, for these purposes, to be the state of interoperability among the agencies' information processes that produce the maximum feasible synergy. This state of synergy is achieved when all needed information about the transportation system and its traffic are collected by the most appropriate agency (and function within the agency), and all information is shared with all legitimate users.

Integration of the information processes of these agencies will require an incremental approach over some time period. The first step in the process is to simply share all currently available data among the agencies. If efficient access mechanisms are provided, and users begin to make good use of the data, they will begin to request changes that make the data more useful for their functions. The users collectively, with the assistance of information specialists, should then consolidate their needs and specifications into a consistent set of data requirements. Good management, faced with the usual limitations on resources, will negotiate the most synergistic relationships among themselves.

A very important point to be made here is that modem information technologies are essential to making this integration feasible. The traditional paper based information systems and files that have been in use for centuries do not allow the efficiencies in information processes that make this integration desirable.

The suggested first step, that of sharing currently available data, will require standard databases and mechanisms for sharing the information among agencies. These two items will be discussed later. Once standardized and shared databases exist, the common functions of the agencies can also be improved by the development and use of modem information systems and technologies. For example, standard application programs, standard database access protocols, and user interfaces would make the sharing of information products extremely efficient.

The following paragraphs discuss some of the most important aspects of the envisioned integrated Transportation Information System (TIS).

4.1 Information Standards to Enable Sharing. Four of the obvious categories of standards that must be developed to allow efficient sharing of data between agencies are as follows:

4.1. I Identifiers for Transportation System Components and Other Objects - A common scheme must be developed or adopted for uniquely identifying each of the transportation system's components and other objects of interest. Independent identification schemes are currently being used by different agencies, *and sometimes within different partsof the same agency.* Sharing information about objects with different identifiers is very difficult. As an example, the same road segment, or different segments of the same extended road, will have different national, state, county and city names or numerical designators. This problem also exists for other system components or objects of interest that have multiple or changeable names, such as airports, bridges, hospitals, etc. Common and stable identifier schemes must be developed and used. The selection of a standard identification scheme for transportation system components and other objects of interest should consider and be coordinated with any related national and international efforts that may exist.

4.1.2 Geographical Reference Scheme - A common scheme must be developed or adopted for defining the spatial parameters of the transportation system's components and other objects of interest (particularly location and dimensions). There are many reference methods currently being used, and sharing data referenced with different schemes is very difficult. In some cases, multiple geographic references are used within the same agency, and there are usually differences between agencies. This is a critical obstacle to efficient sharing of information among jurisdictions. The selection of a standard geographical reference scheme should consider and be coordinated with any related national and international efforts that may exist.

4.1.3 Data Definitions - As with data representation, standards must be developed for the most common data items to define their meaning and perhaps their method of calculation or collection. This is essential if shared data is to be understood and used properly. Examples of data needing such definition are pavement condition descriptors, traffic and vehicle parameters, vehicle classification, commercial load descriptions, etc. Standard definitions do exist for some of the most widely used data, such as traffic parameters, but even these standards are not universally adhered to. The selection of standard data definitions should consider and be coordinated with any related national and international efforts that may exist.

4.1.4 Data Representation Standards - Representation standards (data structures and individual datum formats) must be established for each of the data types used in the transportation agencies (alphanumeric, GIS, CAD, graphics, images, video, photogrammetry, etc.). Among various federal, state and local agencies, use of different data representation standards are common. Even within a single agency, different representations are sometimes used for similar data. This usually results from the selection of systems from competing vendors with proprietary data representation schemes. Standards may exist or may be under development for some of the data types of interest. The selection of data representation standards should consider and be coordinated with any related national and international efforts that may exist.

4.2 Mechanisms for Information Sharing. There are several possible mechanisms for sharing the information among the agencies, even from a standard database. This discussion will explore these possibilities as a way of developing the argument for the preferred mechanism.

The simplest and least preferred sharing mechanism is by exchange of printed copy or digital recordings of the information on diskettes or magnetic tape. The exchanged information must be manually transported between the agencies.

This exchange mechanism can be improved if the agencies are interconnected by an electronic communication network capable of transmitting the shared information types. For alphanumeric type data, this is not a problem. Other data types are more difficult, but becoming more commonplace daily.

Even with interconnecting communications networks, information exchanges will, unless deliberately arranged otherwise, require a request from the user and a response from the keeper of the information. This is an impediment in that it introduces delays to the user and causes work load for the database keeper.

If these agency databases are kept on-line, the most efficient possible access can be provided to all legitimate users. Care must be taken, of course to protect the database, and not all information in the database can be shared with all users. All modern database systems have the capability to enforce these sorts of restrictions on the agencies databases. This, then, is the recommended approach for the TIS databases within all transportation agencies.

4.3 Recommended Structure for TIS Information Processes and Interfaces. The recommended structure of the TIS from an information processes and interfaces viewpoint is depicted in Figure 1 and is discussed in the next few paragraphs.

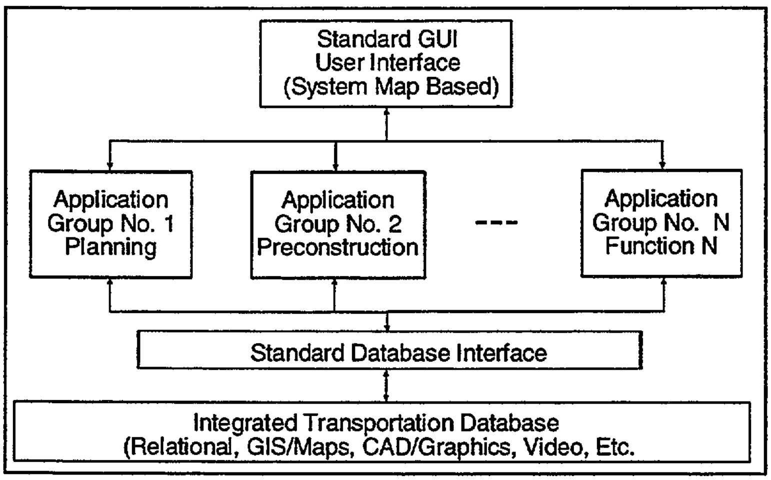

Figure 1. The TIS Information Process Structure

4.3.1 User Interface - The idea that a road system and its components can be represented on a map is the inspiration for the user interface. The user interface is envisioned to be a combination of a Graphical User Interface (GUI), menus, and forms, probably with a command line for expert users. The GUI will be based on a map that potentially contains all objects of interest to the transportation functions, as well as jurisdictional boundaries and other features useful in determining the scope of the user's interests. The menus will allow the user to initially select the applications programs that he/she will employ, to select specific work activities to be performed within the application, and to indicate the jurisdictional areas and the classes of map objects to be displayed. Forms will be used to solicit information from the user and to provide output to the user, as is appropriate for the selected application and work activity.

4.3.2 Application Processes/Components - Each of the major transportation functions will have a set of applications (both hardware and software). Each application will implement some part of an elemental function within the major functions. An elemental function is one that achieves a limited and specific objective for which the internal "functional activities" are straightforward and readily identified; and the elemental function is comprised of a set of generic functional activities. Functional activities are the work elements within an elemental function. The generic functional activities are: Obtain inputs; extract relevant information from the inputs; identify problems or objectives from the input information; devise or select a response; implement the response; and sometimes, monitor the effects of the response (with adjustments as necessary).

Each application will assist the user in performing the functional activities to the degree feasible with information technology. In many cases, the elemental functions are or could be performed by standard methods among agencies, possibly using standard application programs. In fact, some trends in this direction were seen in GDOT. If done well and widely accepted, such standard transportation application programs would dramatically reduce development costs for effective information systems, and simultaneously produce significant integration benefits.

4.3.3 Standard Database Interface - To provide maximum independence of computer component vendors, both hardware and software, it is necessary to provide a standardized interface between the application programs and the Database Management System.

4.3.4 Database - The structure of the road system and its hierarchy of components, the roles of each component, and defined relationships among the components all indicate an object-oriented relational database. It is recommended, then, that the standard database for integrating transportation agency information processes consist of a relational database, with a data structure that can accommodate any and all of the types of information that define the system components and their usage (traffic). The relational database will not contain the large files necessary for Computer Aided Design (CAD), video, and possibly other types of data. These data will be located in separate databases, indexed to the relational database. The key reference (index) for all data will be the unique identifier for any object on the GUI map.

4.4 **An Architectural Structure for TIS Subsystems.** The architectural concept for the TIS is a distributed processing and database system of the client-server type. This implies a mixed processor environment, interconnected via data communications network(s), with the numerous "client" applications being "served" by a fewer number of database/file server processors. This architectural concept is depicted (for a single location) in Figure 2. TIS subsystems such as that represented by Figure 2 will be located at each major location within each agency. Wide Area Network connections would interconnect the agencies and their external partners, whether local, within the state, national, or international.

4.4.1 Client Processors and Application Programs - Most transportation application programs are expected to run on high end PCS; i.e., with Intel 486, Pentium, or equivalent processors. The more demanding applications may require more powerful workstations. Each application will provide integrated support of all activities within a transportation function, and wili be able to locate and automatically retrieve necessary input data from the database, and will automatically deposit the application's processing results back in the appropriate database files.

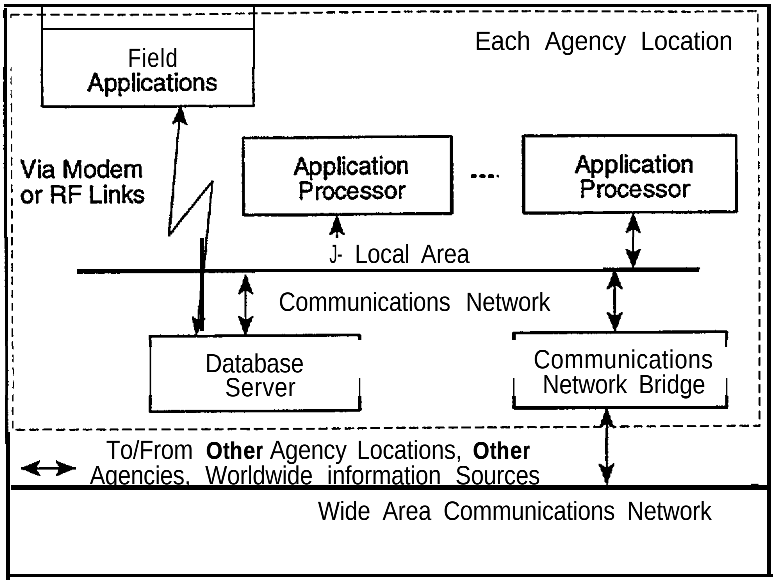

Figure 2 The TIS Overall Architectural Concept

4.4.2 Database System - The database system will consist of special processors, software, storage devices, and any other hardware necessary to provide full life-cycle management of the several types of information used in the TIS. These information types include:

- alphanumeric data in a standard relational table format,
- spatially tagged information for GIS or other geographically oriented uses,
- CAD files or other graphical information in a standard format, and
- Static images and dynamic video of transportation oriented subjects.

Other categories of information requiring separate database subsystems may be identified in the development of TIS subsystems. *It is important to emphasize the cradle to grave information management concept.* The database system must provide appropriate storage and retrieval responsiveness based on the activity level associated with any piece of information.

4.4.3 Data Communications NetworkBystem - It is anticipated that the application processors and the file servers will be interconnected via standard data communication networks. Local Area Networks (LANs) will interconnect individual users/processors within an agency operating location when a single building or several closely clustered buildings are involved. The various agencies and widely separated operating locations within an agency will be interconnected via Wide Area Networks (WANS), which will actually interconnect the LANs.

5.0 RECOMMENDED APPROACH TO IMPLEMENTING THE TIS

In order for the TIS to be well integrated and to serve all agencies well, the following development priority is recommended :

- Necessary information sharing standards should be developed first,
- The standard databases should be designed (implemented later by function),
- The database and communications *systems* should be developed next,
- Develop other common components, and select frequently used components,
- The applications should be developed and databases implemented for each function in order of priority.

Each of these development steps are addressed hereafter.

5.1 Develop Transportation Information Standards. These standards should be the top priority, since they enable efficient information sharing, and would provide significant benefits if no other actions were taken. These are the standards discussed in Section 4.1.

5.2 Design Standard, Integrated Database for all Information Types. A standard database, which is the foundation for integrating the information processes among transportation agencies, should be the second priority. With information standards in place, a standard database design would provide significant integration benefits even if no further integrating actions were taken. The standard database design should be based on object-oriented relational database technology, modeled using the transportation system components and other objects of interest discussed earlier, and providing potential storage locations for all system and traffic information types. The databases of the several types of data (relational, GIS, CAD, graphics, images, video, etc.) may require different designs, but must be integrated via the relational database.

A common database interface must be selected (or developed if necessary) and incorporated into the applications and the database system. The Open DataBase Connectivity (ODBC) is an example that bears consideration.

5.3 Develop the Database System and the Communications Systems. These are the common components that provide the hardware and software for hosting the database, and provide an efficient sharing mechanism among the agencies.

<u>Database Systems</u> - The third priority is to select, procure and install database *systems* (hardware, software, etc.) at those agencies that desire to share information. Separate database systems may be required for some of the information types; i.e., the relational, GIS, CAD, graphics, image, video, photogrammetry, etc.

<u>Communication Network</u> - The basic requirement for the communications network is that it interconnect all agencies (and their internal functions) and support the electronic transport of all categories of information that are to be shared within and between agencies. In developing the communication system, it would be wise to also consider the need to connect the agencies with their customers; i.e., citizens, drivers, travelers, businesses, and other government agencies.

5.4 Develop Other Common Components, Select Commonly Used Components. The two categories of components to be addressed are those common to the entire system, and those that are used by multiple functions within the agencies. The most significant other common component is the user interface, which is considered critical to system effectiveness. Less critical, but nevertheless important are the commonly used components such as GIS, CAD and other such special systems.

54.1 User Interface- The purpose of an information system is to assist a human user in performing functional activities, except in the rare case when the activity can be fully automated. *The key to providing efective assistance is the interface between the computer and the user.* This interface must be intuitive and easy to learn for a user with average computer skills and an understanding of the functional activity being performed. To maximize the transferability of skills, the interface should be as standard as possible among transportation functions. As discussed earlier, the user interface is based on a map of the transportation system within an agency's jurisdiction, with menus, forms, etc., to select and perform the user desired function, work activity, and information process.

5.4.2 Commonly Used Components - Eventually, information standards will be complete and specific enough to assure interoperability among GIS, CAD, graphic, video, etc., systems from different vendors. After this situation exists, the selection of "standard" systems that use and generate these classes of information will be unnecessary, and would indeed be unwise. However, at least in the near future, it is unlikely that the information standards will be robust enough to guarantee interoperability. To assure that information products in these classes can be shared among transportation functions and agencies, it may be necessary to select specific vendors (perhaps multiple vendors) of these special systems.

5.5 Develop TIS Subsystems to Support Elemental Functions in Priority Order. The TIS subsystems, which consist of specific applications and their databases to support elemental functions, should be developed in the order of their priority. This prioritization must be done on an agency basis. Specific criteria that were used to develop the priorities for GDOT are:

- The degree to which information systems are mandated to support specific elemental functions by federal, state or local governments,
- The degree to which the elemental function's efficiency will be improved,
- The scope of the elemental function's impact on other agency functions,
- The scope of the elemental function's impact on external agencies,
- The dependencies among the agencies elemental functions, which may dictate implementation sequence, and
- The complexity of the elemental function, which correlates to cost and the need to consider budget constraints.

E-Z-PASS AND TRANSMIT USING ELECTRONIC TOLL TAGS FOR TRAFFIC MONITORING

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E-Z-Pass and TRANSMIT
Using Electronic To11 Tags for Traffic Monitoring

Abstract

The New York State Thruway Authority, along with its partners in the Northeast is phasing in an electronic toll tag (E-Z-Pass), primarily for the collection of tolls from pre-paid accounts. One of the potential benefits of this system is being explored through the use of these read-write tags as probes in a 30 km (19 mile) interstate corridor. Using roadside readers at 2.4 km (1.5 mile) intervals, the TRANSMIT system tracks cars with these tags, monitoring for average speed and thus traffic density. The data is gathered at a regional traffic monitoring center (TRANSCOM). Initial results from this FHWA-funded operational test indicates that this is a useful system for speed monitoring and incident detection. Future use could be extended to connecting roads where there is a significant portion of motorists with toll tags.

Introduction

In 1993 the New York State Thruway Authority (NYSTA) began deployment of a system of electronic toll tags to replace the use of toll tickets and allow vehicles to pass through toll barriers without stopping. At the same time, an experimental system was proposed to use those vehicles with toll tags as probes in a 30 km (19 mile) long stretch of the Garden State Parkway (GSP) in New Jersey and I-287 in New York. This system is called TRANSMIT (the TRANSCOM System for Managing Incidents and Traffic). Using these probe vehicles, a computer system and its operator would be able to monitor travel times and speeds on the roadway. The system also would be able to detect an incident as indicated by a sudden drop in speed or lack of vehicles arriving at a monitoring point within an acceptable time period.

While the prime mission of the TRANSMIT. system is incident detection, it compiles and stores travel time data on discreet highway segments. This type of system allows the installation of readers to detect vehicles much in the way a loop system works, at comparable cost.

E-Z-Pass

In early 1993, NYSTA began deployment of E-Z-Pass, a system that used windshield mounted read-only electronic tags and readers in toll lanes that automatically deduct tolls from a pre-paid account. One of the initial usages for these tags was on the Tappan Zee Bridge, which carries 120,000 vehicles on I-87/I-287 across the Hudson River each day. Currently, 70% of the vehicles in the am peak hours are using the E-Z-Pass tags at this site. The system has expanded to other barriers and, by the end of 1996, is expected to cover the most of the 800 km (495 mile) Thruway mainline.

In 1995, this system was upgraded with new tags, readers and software to a read-write system. This was done to be compatible with NYSTA's regional partners in the E-Z-Pass effort. When fully implemented, toll readers could be in place along toll facilities throughout New York, New Jersey, Pennsylvania and Delaware. TRANSMIT or other monitoring readers could be erected along these toll routes as well as feeder routes which have a significant toll tag population.

The tags are actually plastic cases about the size of a cassette tape and contain what is known as a read-write device. The circuitry contains a low power radio frequency transmitter and receiver, as well as a processor, a small memory and a battery. The tag is affixed to the inside of the windshield behind the rear view mirror with velcro strips, allowing it to be removed or transferred between vehicles. In operation, the tag is dormant until it comes within range of a reader. The reader, which is a low power transmitter-receiver installed overhead or on the roadside sends out a signal which activates the tag. Upon making contact, the tag identifies itself to the reader. In the case of TRANSMIT, this identification is entered into the system for processing.

TRANSMIT

TRANSMIT was developed during 1993-94 to establish the feasibility of using Electronic Toll and Traffic Management (ETTM) equipment for traffic surveillance and incident detection applications. The system required the installation of toll tag readers at regular intervals along the test corridor. The readers are installed under bridges or sign trusses for overhead detection or pole mounted for side fire detection. Each reader has a "capture zone" approximately three to six meters (l0-20 ft.) wide. The next generation readers will have a zone width of 30 to 60 meters (100-200 ft.). This will enable the system to use one reader where two or more are now used to cover a site. Also, the new readers will be able to "talk" with several vehicles at once, rather than singly as is the case now. The readers are connected to ground mounted cabinets housing power and communications equipment. Signals from the sites are sent over leased phone lines to TRANSCOM's Operations Information Center (OIC) in Jersey City, New Jersey.

When a vehicle's tag is detected, the identification is sent to the OIC. The system then anticipates receiving a signal at the next reader downstream. Since the vehicle's travel time can be measured between two readers at a known distance apart, the space mean speed can be determined. Space mean speed is defined as:

$$\text{Space Mean Speed} = n\frac{\text{Distance}}{\sum t}$$

where n equals the number of vehicles in a given time period and Σt equals the sum of travel times of those vehicles.

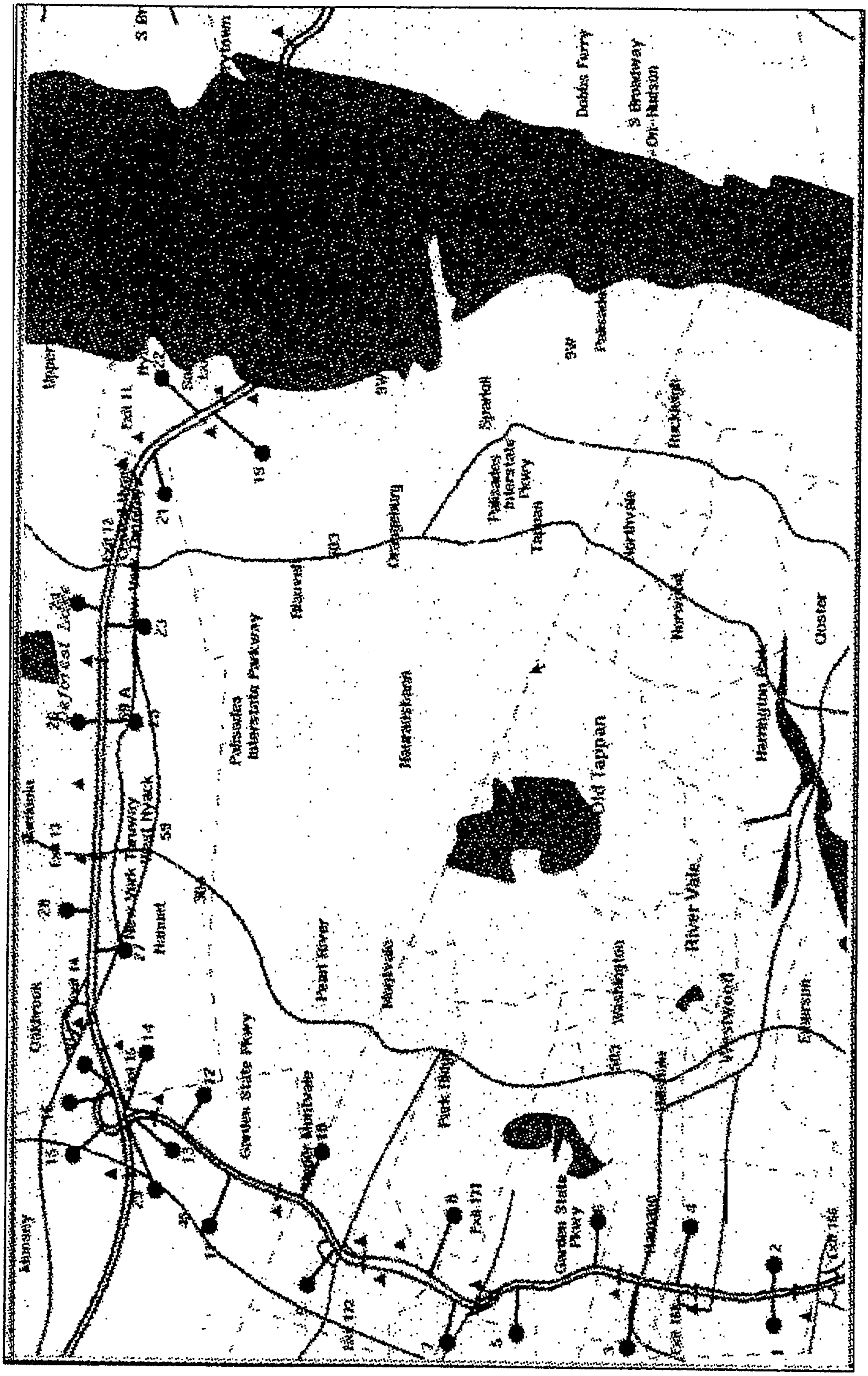

Figure 1:
TRANSMIT
Main Screen

Given a sufficient number of vehicles, a space mean speed for the link can be established. The mean speed, along with the associated standard deviation, is determined in 15 minute intervals. These values are saved and incorporated into an historic database for that time increment. Travel times and average speeds are saved in the categories of weekdays, Saturdays, Sundays and holidays. One could therefore look up the historic average time increment and speed for a specific link and direction for a weekday between 7:45 and 8:00 am.

Of course the speed estimate is only good for the tagged vehicles which are detected by the system. The percentage of vehicles in the stream which are tagged can be determined easily if the readers are being used on a toll facility. On connecting routes where tags are not counted by the toll facility, counts must be taken by conventional methods to determine the average vehicle counts, especially during the peak hours, to determine the percentage of vehicles with vehicle tags. Experience has shown that the tag percentage is greatest during the peak am period weekdays, when commuters are going to work. The pm peak hours show the next greatest percentage of tagged vehicles. When there is a sufficient percentage of tagged vehicles in a busy section, say 5 to 10% of 2000 vph, then a reasonable sample can be obtained - 100 to 200 tagged vehicles/hr or 25 to 50 tagged vehicles per 15 min. period.

The actual processing of this data is performed on a micro-computer which is fed by the server which receives the signals from the readers in the field. The processing software uses an Oracle 7 SQL database. The signals come in to the OIC via a leased phone line from a central hub which collects incoming signals from the readers. The exception for this are the readers on the Tappan Zee bridge, which use a radio to transmit to a receiver and then to phone lines.

The main screen (Figure 1) has a map of the area indicating the roadways with the segments included in the TRANSMIT project. Each segment is color coded for quick reference and response by the operator. One segment is defined as the portion of roadway in one direction between two readers. When traffic is flowing at 80 kph (50 mph) or faster, the segment is colored green. Tf the space mean speed drops below that, the map segment turns yellow. Below 48 kph (30 mph), the segment color turns to red. If a reader becomes inoperative or loses communication, the segment turns black. The system automatically skips that reader and the next reader takes its place. This way there is still coverage, however it now on a longer segment. Attached to each segment is a symbol that looks like a lollipop. The lollipop represents the incident status on its segment. Normally blue, the lollipop turns yellow when the system sounds an alarm for that segment. When the operator confirms an incident, the lollipop turns to red until the incident is cleared, at which point it resumes its normal blue color. Also on the map are 22 triangles, each one represents a reader on the system. There is also an option which allows the operator to zoom in on a portion of the screen.

The most significant feature of the system is shown in Figure 2. Here against the background of the main screen is a window showing the data for a particular segment. Listed are:

- Historic Arrival Time - The average for the given time period and type of day, it is constantly updated with the latest information.

- Mean Current Arrival Time This is the Space Mean Speed for the current segment and time frame.
- Number of Non-Arrivals - The number of vehicles expected in the period that are late. A vehicle is considered late by the system if it has not arrived within three standard deviations of the historic arrival time.
- Cars in Average - The average number of vehicles in the historic time period.
- Average Speed - The average speed for vehicles during the current period.
- Time in Average - The average travel time for the vehicles in this period.
- Confidence Level - A thermometer style display indicates the confidence level of the possibility of an incident. As more cars are late in the segment, the confidence level increases.

The software will allow the user to save data in blocks (e.g. February 1, 1996 11:00 am to 1200 pm) in addition to blending it into the historic database. The historic data can also be altered to save data by day of week or to separate holidays (Christmas vs. July 4 vs. the day before Thanksgiving, etc.). This feature would be of greatest benefit to those interested in growth patterns, changes in traffic patterns and the like.

Accuracy

One of the concerns with any new system is accuracy, and by extension, reliability. The most recent analysis of accuracy (August '95) was conducted on a section carrying vehicles over the Tappan Zee bridge. That analysis showed that 85% of the tagged vehicles were detected. Some of the misses could have been from people who remove their tags when not at a toll plaza. After this test adjustments were made to the system which should have resulted in improved performance. Each segment has is own idiosyncracies which must be adjusted. For vehicles which have their tags properly mounted, the accuracy of detection is above 90%. The system has shown that it is not affected by adverse weather conditions. During the cold and snow of the recent 'Blizzard of '96", the system was monitoring traffic without noticeable impairment.

During all of 1995, there were three incidents when a reader became inoperative. Two were due to lighting strikes and the third due to an accident involving a truck.

As the system expands, it is anticipated that arterials will be monitored as well as interstates. These roads will be more difficult to monitor and therefore have a lower accuracy. By their nature, arterials have more and closer spaced access points. Having more places for traffic to exit would cause a greater number of late arrivals and thus more false alarms. This can be compensated for by increasing the number of readers and reducing the link lengths. This in turn would increase the cost on a unit length basis.

Mm-is

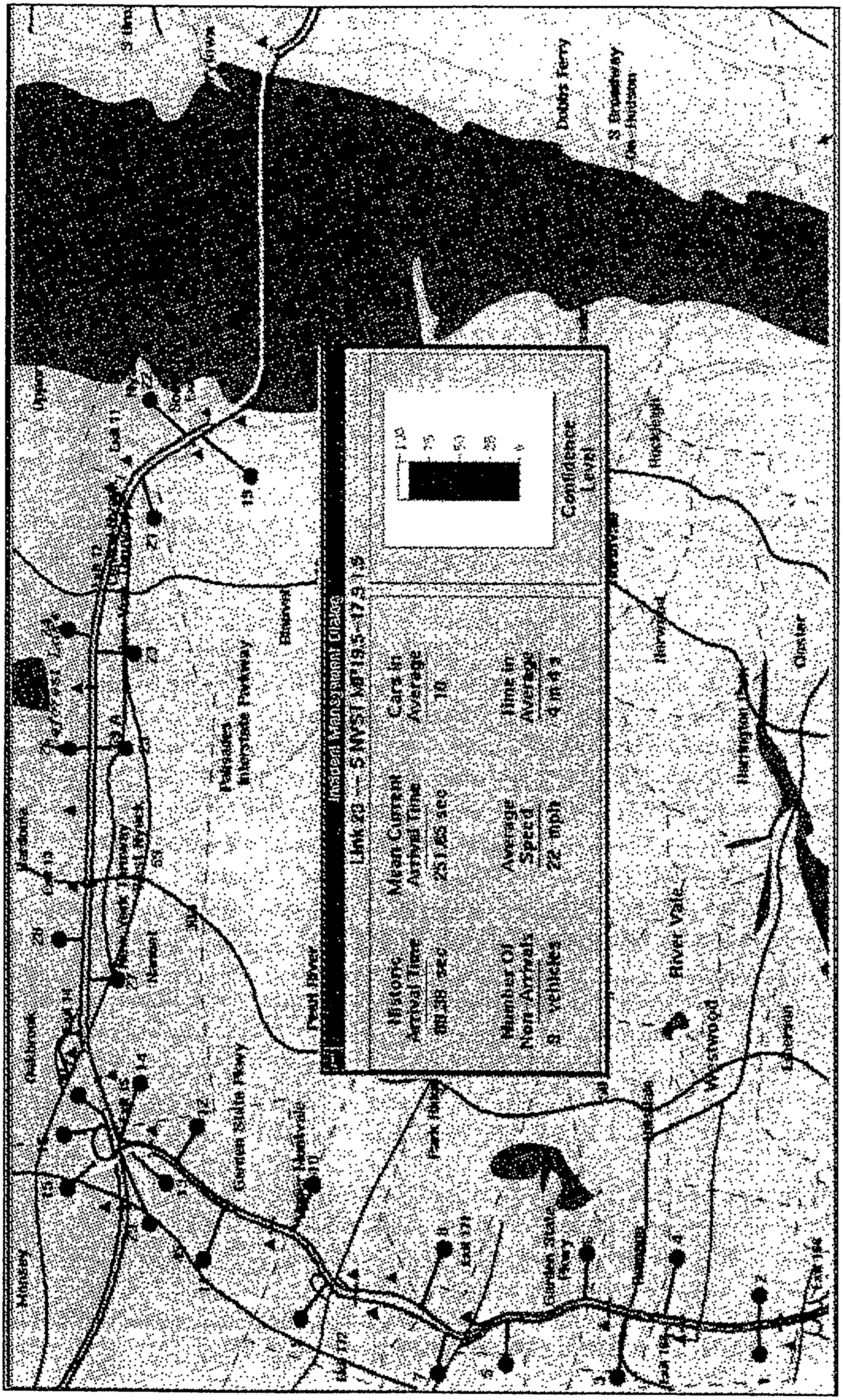

Figure 2

Security

The introduction of toll tags has raised the issue of privacy in New York just as in other areas. The governments ability to identify the location of a persons car has caused varying degrees of concern about Big Brother among E-Z-Pass users and non-users alike. Some motorists see this as an interstate speed trap. Others are concerned that they are being watched without their consent or knowledge. Obviously this is not the intent of the system, and steps have been taken to reduce the grounds for these fears.

When a vehicle passes a reader, the toll tag is prompted for au i.d. number. The number is sent to the reader and then to the OIC, where it is automatically scrambled by the system. The system operator can call up a screen showing a list of transactions including link number, reader number, time of read and vehicle i.d. At the end of the 15 minute time interval, the data for each segment is blended into the historic database for that time increment. The individual vehicle records are automatically erased. The system operator has no idea of who owns the vehicles, much less who is in them. Data is collected solely for the purpose of monitoring travel time and incident detection. There is no involvement with any police agency with regards to speeds, etc. If traffic in a particular segment is running above the legal limit, it doesn't take TRANSMIT to alert the police to this.

Costs

During the development of this project, cost was considered for every item, primarily with the selection of hardware for communications. One of the biggest start-up costs in the project is the link between the readers and the OIC. Different technologies were considered, including spread spectrum radio, leased lines, fiber optics and satellite transmission- Radio is low powered and low cost, which makes it desirable in areas where you have line of sight between radios and receivers. Radio is used for the sites on the Tappan Zee bridge which has no real obstructions. Satellite time is very expensive, therefore this option was ruled out early in the process. The most economical choice for most of the system was leased line. Each of the stations is connected to a central point on the GSP, from which the lines are multiplexed into a single line to the OIC.

The cost of each reader site ranged from $30k to $5Ok including all appurtenances. The remainder of the system including communications set-up, hardware and software development was $1.1 million.

Future Directions

As initially stated, this whole project is an operational test to see if traffic flow and incidents can be managed using electronic toll tags which already have been deployed. Having proven that this is a viable method of traffic detection and monitoring, the next logical step is the physical extension of the system and fuller use of the software's capabilities. Ofticially, the project is still under way, with a completion date of December 31, 1996. At that point a report will be submitted to FHWA analyzing the system's performance. Maintenance thereafter will become the responsibility of

TRANSCOM and its member agencies.

The E-Z-Pass tag system is being extended in the New York City area over the next several years. The Verazzano Narrows bridge between Staten Island and Brooklyn is now accepting E-Z-Pass tags. TRANSMIT will be used in the corridor that includes the bridge. TRANSMIT is also being extended along I-287 from the Tappan Zee bridge to I-95 at the Connecticut state border. The TRANSMIT expansion on I-287 is being underwritten by the New York State Department of Transportation (NYSDOT). This new segment will have readers spaced every four miles, which will allow for greater coverage per dollar, however at lower accuracy. E-Z-Pass is being extended northward on I-87 to Albany this spring and westward along I-90 to Buffalo by the end of the year. This last extension would allow TRANSMIT or a similar system to operate through nearly all of New York State's population centers, including intersecting Interstate routes. The E-Z-Pass system is also expected to be on line on toll roads across Pennsylvania and New Jersey in the next two to three years.

At TRANSCOM, efforts will be made to expand and refine the operation of the software. The type of day option will be expanded to allow for historic averages for different holidays as well as, days before and after holidays and weekends. Fortunately, the project is still under development and the vendor is still under contract to make changes as desired.

Other potential uses for this system include generation of origin/destination data, variable message sign interaction and in-vehicle motorist information. These last two are dependent upon the tags' ability to receive information, the former is a function of the system software.

Conclusion

The TRANSMIT system is proving itself to be a useful tool in the areas of incident detection and traffic flow monitoring. Vehicles which have electronic tags are providing data for a complete and instantaneous picture of traffic conditions on a 30 km system carrying as many as 30,000 vehicles at a time. Incidents have been detected quickly, allowing them to be swiftly cleared. A database of traffic volumes, travel times and average speeds - all in 15 minute increments - has been amassed for a period of one year. This database has the potential to be further refined to save each block of data individually, rather than blending into an historic average. The system has shown itself to be highly accurate and quite dependable. This type of system has shown that it is an effective means of traffic monitoring in an area of high traffic that has a significant presence of electronic toll tags.

Notes:

TRANSCOM (Transportation Operations Coordinating Committee) is a coalition comprised of Amtrak, FHWA, NJDOT, NJ Highway Authority, NJ State Police, NJ Transit, NJ Turnpike Authority, NYCDOT, NYSDOT, NY State Police, NYSTA, Metropolitan Transportation Authority, Triborough Bridge & Tunnel Authority, Palisades Interstate Park Commission, Port Authority of NY & NJ and Port Authority of Trans-Hudson. It's purpose is to coordinate transportation activities in the New York City metropolitan area.

IMPROVED VEHICLE OCCUPANCY DATA COLLECTION PROCEDURES
(EXTRACTED PORTION FROM REPORT PREPARED FOR FEDERAL HIGHWAY ADMINISTRATION)

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Battelle

Authors: Kurt K. Heidtman, et al.
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EXECUTIVE SUMMARY

Transportation planners and policy makers are increasingly concerned with improving the efficiency and effectiveness of transportation investments. One factor that contributes greatly to total mobility is the average number of occupants in automobiles. There are a number of different methods for collecting vehicle occupancy (VO) data, including: windshield/roadside observation, carousel methods, photography, mail out surveys, and analyzing accident data. However, each method has its own unique strengths and weaknesses, and little research has been conducted to compare the various methods with each other.

This project, funded by the Federal Highway Admiistration's Offices of Highway Information Management and Environment and Planning, evaluated these five primary vehicle occupancy data collection methods in five different metropolitan areas across the U.S. The areas included in the analysis were: Albany, New York; Baltimore, Maryland; Chicago, Illinois; Louisville, Kentucky; and Spokane, Washington. These areas were selected based on expressed interest in the project, some VO data collection work already planned in their areas, time table for their VO data collection effort, and other factors.

Although this project is still being conducted and final conclusions have not been prepared, preliminary results indicate that all five methods considered have potential for collecting VO data. However, the following preliminary conclusions can be drawn:

- by far the most common method is the windshield/roadside observation method. This method was used in nearly every metropolitan area, and is generally considered the most accurate. However, this assumption may be exaggerated, at least under certain conditions, based on comparison with the carousel method.

- a new VO data collection method, known as the "carousel method," offers promise for collecting improved data on multi-lane routes with high traffic flows. This method involves an observer traveling in a car moving slower than the general rate of traffic Given the proximity of the observer (often only a few feet), better views of the front and rear seat passengers can be obtained, especially in vans and automobiles with tinted windows. However, fewer vehicles can actually be observed than the windshield/roadside method, so estimates are based on a subsample of available data.

- mail out ***surveys*** can be used to gather VO data, but the development and deployment of mail out surveys requires considerable time and planning. These surveys can generate additional useful information, such as trip purpose, which the other VO data collection methodologies cannot.

- the least preferred, based on test results, was photographic VO data collection. This includes both still and video photography. Based on the metropolitan planning organization testing this method, they found that greater labor was required than other methods because a person still had to review photograph video, plus the time and resources required to install, uninstall, and secure the photographic equipment.

- accident data extraction is an indirect method of collecting VO data that probably offers the greatest promise of generating VO data at the lowest cost, at least in those areas in which the data is recorded. The methodology involves reviewing accident data records, collected by police, in which the officer records the number of occupants of each vehicle involved in an accident. Some concerns have been raised that accident data may not be representative of the overall traffic stream--that is, higher or lower occupancies may have a greater chance of being involved in an accident. Potential biases in this data were investigated.

Later phases of this study intend to examine some of the issues presented in this paper in more detail. Specifically, the cost effectiveness of the various methods will be discussed, the strengths and weakness of accident databases in predicting VO will be analyzed (only data from one area was included in this report), and the prospects for expanding VO data collection into transit and other modes will be explored. This project is planned for completion by the end of 1996, assuming that data collection from all the areas is completed by the summer. A final report will be prepared and submitted to FHWA.

4.0 CONCLUSIONS AND FINAL COMMENTS

Vehicle occupancy is an important performance measure for gauging the effectiveness of ridership programs, HOV projects, and, in general, the efficiency of transportation facilities. This project has concluded that there are several practical methods for obtaining useful AVO estimates. However, each of these methods have positive and negative attributes. MPOs developing a regional vehicle occupancy program should consider these attributes and select the method or a combination of methods which meet their requirements for the given conditions and constraints of the metropolitan area.

Roadside/Windshield Method

The roadside/windshield survey method is the most commonly used method, but it has several potential shortcomings:

1. When traffic is heavy, and fast-moving, roadside observers may have difficulty counting the number of passengers in passing vehicles.

2. The roadside/windshield method survey causes the greatest disturbance to the normal traffic flow (among windshield, carousel, and video methods), and therefore may be a problem on the basis of safety.

3. The roadside/windshield method may be under-counting vehicle occupants on four lanes or more highways during heavy traffic time periods, when traffic is traveling at the speed limit or higher.

Carousel Observation Method

This data collection technique allows the second staff person in the survey vehicle the opportunity to **view** the normal traffic flow passing him at between IO to 15 mph. It also provides ample time to collect at least two of the three following pieces of data: license plate identification, automobile occupancy, and vehicle classification data. Data collection costs are even further reduced when several adjoining roadway segments of two or more different highways are included in the same survey. Obviously, the cost-effectiveness of this methodology increases proportionately by the number and types of data that can be collected during the same survey.

Preliminary comparisons of the carousel method with the video surveillance method and roadside/windshield method surveys on high-speed highways seem to indicate that:

1. Neither the “carousel” nor the roadside/windshield methods can compare with the absolute public safety provided by the video surveillance method,

2. The roadside/windshield method causes the greatest disturbance to the normal traffic fl ow, the carousel a minimum disturbance, and the video method none to the flow of traffic,

3. There was no public resentment to the carousel method since there is no awareness that a survey is being taken. There is minimal resentment to the roadside/windshield survey, and the greatest resentment to the use of the video observation method (right of privacy),

4. There appears to be greater data accuracy using the carousel observation method than the roadside/windshield methods. There is less data accuracy using the video observation method because identifying the types of vehicles, its number of occupants, or its license plate numbers while actually moving in traffic is more difficult than making those determinations from a fixed roadway position for observers or a camera on the highway,

5. The carousel method "capture" rates **was** lower than the other two methods. However, more than one piece of data could be collected along multiple segments of connecting highways,

6. Considering all of the above factors, certain applications of the carousel method could result in a greater cost-effectiveness than the roadside/windshield and video methodologies.

Mail-Out Questionnaire Survey Method

AVO estimates obtained from response on mail-out questionnaires are very sensitive to the audience targeted and to the wording used in the questionnaire, and was more costly than roadside methods. In addition, if these estimates are to be compared with AVO numbers obtained by observational methods (such as the roadside/windshield or carousel methods), questionnaire responses need to be weighted for some measures of duration or distance traveled. One advantage of the questionnaire **is** the determination of trip purpose by respondent.

Accident Data Extraction Method

Accident data extraction method is the least expensive method to obtain AVO estimates, however, they may be biased and appear to overestimate roadside/windshield estimates. AVO trends associated from accident data can be useful in designing roadside/windshield or other VO studies. There is some evidence to indicate that AVOs are significantly different during different times of day, day of the week, and month or season of the year, for different parts of the country.